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OHIO UNIV. ATHENS DEPT OF ELECTRICAL ENGINEERING
EFFECTS OF HIGH VOLTAGE TRANSMISSION LINES ON NON-DIRECTIONAL B-ETC(U)

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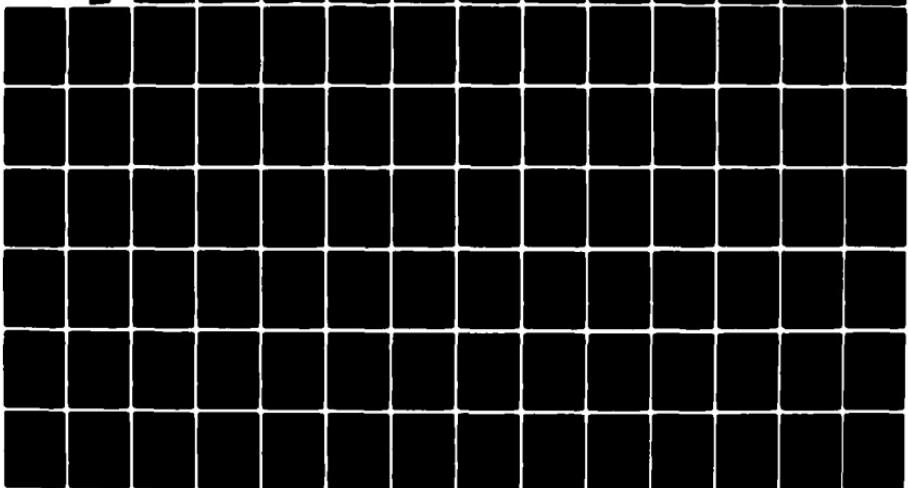
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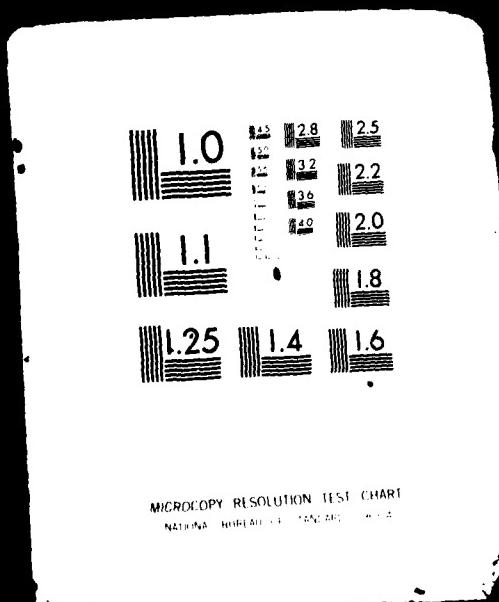
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Effects Of High Voltage Transmission Lines On Non-Directional Beacon Performance

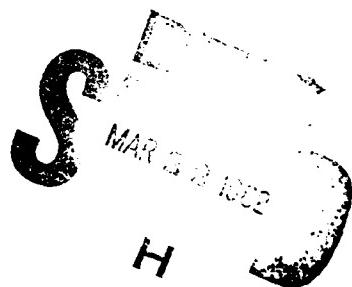
Ismail Ibrahim
and
Raymond Luebbers

Department of Electrical Engineering
Ohio University
Athens, Ohio 45701

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16. Abstract

The potential for high-voltage transmission lines to interfere with the operation of non-directional beacons through the mechanisms of coronogenerated radio noise or passive reradiation of the desired signal has been assessed by use of computer prediction models. The generated noise levels were calculated for both AC and DC lines using methods found in the appropriate literature which have previously been compared with measured data. The reradiated signal levels were computed using a moment-method wire model computer program. This approach was validated by measurements made by the authors and reported herein. For all situations considered, it was concluded that locating an NDB near a high-voltage transmission line should not impair the function of the NDB due to either corona noise or passive reradiation from the line.

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ENGLISH/METRIC CONVERSION FACTORS

LENGTH

To From	Cm	m	Km	in	ft	s mi	n mi
Cm	1	0.01	1×10^{-5}	0.3937	0.0328	6.21×10^{-6}	5.39×10^{-6}
m	100	1	0.001	39.37	3.281	0.0006	0.0005
Km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	2.54×10^{-5}	1	0.0833	1.58×10^{-5}	1.37×10^{-5}
ft	30.48	0.3048	3.05×10^{-4}	12	1	1.89×10^{-4}	1.64×10^{-4}
s mi	160,900	1609	1.609	63360	5280	1	0.8688
n mi	185,200	1852	1.852	72930	6076	1.151	1

AREA

To From	2 Cm	2 m	2 Km	2 in	2 ft	2 s mi	2 n mi
cm^2	1	0.0001	1×10^{-10}	0.1550	0.0011	3.86×10^{-11}	5.11×10^{-11}
m^2	10,000	1	1×10^{-6}	1550	10.76	3.86×10^{-7}	5.11×10^{-7}
km^2	1×10^{10}	1×10^6	1	1.55×10^9	1.08×10^7	0.3861	0.2914
in^2	6.452	0.0006	6.45×10^{-10}	1	0.0069	2.49×10^{-10}	1.88×10^{-10}
ft^2	929.0	0.0929	9.29×10^{-8}	144	1	3.59×10^{-8}	2.71×10^{-8}
s mi^2	2.59×10^{10}	2.59×10^6	2.590	4.01×10^9	2.79×10^7	1	0.7548
n mi^2	3.43×10^0	3.43×10^6	3.432	5.31×10^9	3.70×10^7	1.325	1

VOLUME

To From	3 Cm	Liter	3 m	3 in	3 ft	3 yd	fl oz	fl pt	fl qt	gal
cm^3	1	0.001	1×10^{-6}	0.0610	3.53×10^{-5}	1.31×10^{-6}	0.0338	0.0021	0.0010	0.0002
Liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m^3	1×10^6	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in^3	16.39	0.0163	1.64×10^{-5}	1	0,0006	2.14×10^{-5}	0.5541	0.0346	2113	0.0043
ft^3	28,300	28.32	0.0283	1728	1	0.0370	957.5	60.34	0.0173	7.481
yd^3	765,000	764.5	0.7646	46700	27	1	2590	160.79	6.625	202.0
fl oz	29.57	0.2957	2.96×10^{-5}	1.805	0.0010	3.87×10^{-5}	1	0.0312	0.0078	
fl pt	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.5000	0.1250
fl qt	948.4	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal	3785	3.785	0.0038	231.0	0.1337	0.0050	128	8	4	1

MASS

To From	8	Kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	1.10×10^{-6}
Kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	3.12×10^{-5}
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

TEMPERATURE

$$\begin{aligned} {}^\circ F &= \frac{9}{5} ({}^\circ C - 32) \\ {}^\circ C &= \frac{5}{9} ({}^\circ F) + 32 \end{aligned}$$

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SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
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The mission of the Spectrum Management Branch is to assist the Department of State, National Telecommunications and Information Administration, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world and to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource - the electromagnetic radio frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.
- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.
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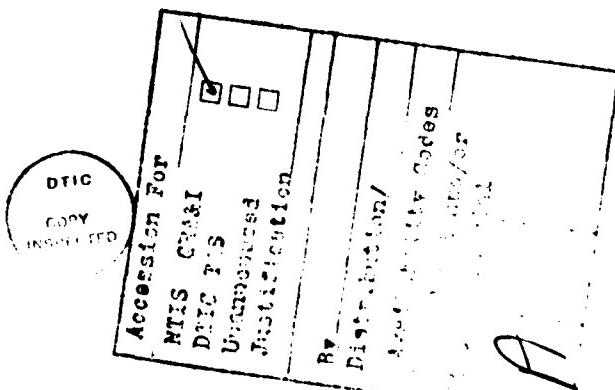


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Chapter 1

INTRODUCTION

1.1 Introduction

The purpose of this report is to provide an engineering basis for predicting the effects of nearby power transmission lines on the performance of Non-Directional Beacons. Two basic mechanisms for possible interference have been considered; Radio Frequency noise generated by the lines themselves, and passive reradiation of the NDB signal by the transmission line towers and conductors. Since the production of radio noise is very different for AC and DC lines, a separate chapter is devoted to each. A third chapter is devoted to reradiation effects (both AC and DC lines will behave similarly). The conclusions reached are discussed in a final chapter; however, the fundamental conclusion is that locating the NDB transmitter near a power transmission line should not have any detrimental effects due to the above mechanisms. It must be immediately pointed out, however, that other mechanisms, such as powerline carrier radiation, are not included in the above statement.

In this report the signal from the NDB transmitter is the desired signal, and the RI noise from the powerlines or the reradiated signal from the powerline structures the undesired. The FAA Handbook¹ states that if the level of the undesired signal is 15 dB below that of the desired signal, the ADF positioning error will be less than ± 1 degree. This criteria will be applied throughout this work for assessing the potential of interference.

The objective of this report is to provide a theoretical capability to predict the critical distance between the powerlines and receiving aircraft where the ratio of the desired signal/undesired noise is 15 dB as a function of effective radiated power of the NDB transmitter, relative permittivity and ground conductivity of the earth, powerline parameters, distance separating the NDB transmitter and the powerline, evaluation of the ADF receiver and the NDB frequency. This objective has been successfully met. In particular, mathematical models now exist which will provide the desired predictions.

Chapter II

PREDICTION OF RADIO INTERFERENCE NOISE FROM AC POWERLINES

2.1 Introduction

Radio Interference (RI) noise from AC powerlines originates from corona, which is defined as "a luminous discharge due to ionization of the air surrounding a conductor around which exists a voltage gradient exceeding a certain critical value".² An IEEE Report³ states that the RI performance can be divided into three stages: 1) generation, 2) propagation and 3) radiation.

The generation of corona, and therefore RI, is basically a function of factors which can be divided into two categories: i) line design factors and ii) atmospheric and environmental factors. The former includes the diameter and spacing of conductors, phase spacing and phase configuration. The latter deals with the accumulation of foreign particles on the line conductors and weather conditions.

The propagation of RI along the powerlines is primarily a function of the line design and earth resistivity, both of which influence the rate of attenuation of the traveling waves. The radiation of RI away from the powerlines is essentially dependent on the positions of the phases of the lines with respect to the location of the observer.

Studies and reports^{2,3,4} have consistently concluded that the RI noise level is at its peak under heavy rain condition. All predictions of RI noise from AC powerlines given in this report will be for the worst case condition of a heavy rain shower.

2.2 Computation of RI Noise from AC Powerlines

CIGRE/IEEE Survey Results⁴ list various methods for the calculation of RI noise from AC powerlines. They are grouped into two categories: i) the comparative method and ii) the analytical method. The former makes use of an empirical formula developed after a careful measurement study with particular reference criteria. To predict the RI noise level from lines of different designs, various corrections for corona generation, measurement frequency and lateral distance are made based on measurements of the variables involved. The analytical method, on the other hand, makes use of a theoretical characteristic quantity of RI generation which is called the excitation function, and proceeds to compute the total corona currents on the lines and the resulting RI noise field strength at the location of the observer.

The method that will be used here belongs to the latter group and is called the "modal analysis method".⁵ It assumes that the powerlines are a reflection-free system of n ideally parallel conductors at constant height above a perfectly flat conducting ground whose potential is zero. The influence of the ground wires is included in determining the surface gradients, but is neglected for the modal currents. The method is composed essentially of the following steps:

Step 1. Determination of the maximum bundle surface gradient

The maximum bundle surface gradient for each phase can be determined by using a method developed by Markt and Mangele⁶. The calculation is carried out with the assumption that:

- the ground is an infinite horizontal conducting plane surface,
- the conductors are smooth infinitely long circular cylinders parallel to each other and to the ground plane,

- the conductors are equipotential surfaces, with known potentials applied to them, the ground plane is assumed to be at zero potential,
- the influence of powerline towers and of any objects in the vicinity is neglected and
- the horizontal spacing between the conductors remains constant and the height of the conductors above ground is also constant.

The procedures for the calculation of the maximum bundle surface gradient are detailed below:

Step a: Each conductor bundle is replaced by an equivalent conductor having a radius r_{eq} defined by

$$r_{eq} = (n \cdot a^{n-1})^{1/n} \quad (2-1)$$

where: n is the number of subconductors,
 a is the subconductor radius,
 A is the bundle radius.

Step b: With the bundles represented by the equivalent conductors, the total charge on each of them is calculated by the Maxwell potential coefficient method assuming appropriate potentials on the different phases. Any ground wires are also taken into account. Program CHARGE listed in Appendix B is used to compute the values of the total charge q_t on the bundles.

Step c: The average bundle gradient is calculated as:

$$E_{av} = \frac{q_t}{2\pi\epsilon_0 \cdot n a} \cdot \frac{1}{A} \quad (2-2)$$

Step d: Finally the maximum bundle surface gradient is obtained as:

$$E_m = E_{av} \left(1 + (n-1) \frac{a}{A} \right) \quad (2-3)$$

Step 2. Determination of RI excitation function under heavy rain conditions

The excitation function is considered to be the specific measure of the cause of RI. It is related to the induced corona currents by the equation⁷

$$i = \frac{C}{2\pi\epsilon_0} \cdot \Gamma \quad (2-4)$$

where: i is the induced corona current injected per unit length of the conductor,

C is the capacitance of the conductor

ϵ_0 is the permittivity of air,

Γ is the excitation function.

In this analysis, an empirical formula developed by EPRI⁸ will be used. For each phase, the value of excitation function Γ is given by:

$$\Gamma(n,d) = 78.0 - \frac{580.0}{E_m} + 38.0 \log \left(\frac{d}{3.8} \right) + K_n \quad (2-5)$$

where $\Gamma(n,d)$ is the excitation function for a bundle of n subconductors of diameter d (cm) in units of dB above $1 \mu\text{A}/\text{m}^{1/2}$,

$$K_n = 7 \text{ dB, if } n = 1,$$

$$K_n = 2 \text{ dB, if } n = 2,$$

$$K_n = 0 \text{ dB, if } n \geq 3.$$

Step 3. Determination of the geometric matrix [G] of the powerlines

From the powerline configuration, the elements of the geometric matrix $[G]$ can be calculated with the equations⁸

$$g_{ii} = \ln \frac{2h_i}{r_i} \quad (2-6)$$

$$g_{ij} = \ln \frac{D_{ij}}{d_{ij}} \quad (2-7)$$

where: h_i is the height above ground of the i th conductor,
 r_i is the radius of the i th bundle conductor,
 D_{ij} is the distance between the i th conductor and the image of
the j th conductor in the ground plane,
 d_{ij} is the distance between the i th and j th conductors.

Step 4. Determination of the modal transformation matrix [M]

The RI propagation along the powerlines, including the corona generated current along the conductors, can be written by the equations⁵

$$\frac{d}{dx} [V] = - [z][I] \quad (2-8)$$

$$\frac{d}{dx} [I] = - [y][V] + [J] \quad (2-9)$$

where: $[V]$ is the column vector of voltage on the line,
 $[I]$ is the column vector of current on the line,
 $[J]$ is the corona current density injected on the conductor,
 $[z]$ is the square matrix of series impedance per unit length of
the line,
 $[y]$ is the square matrix of the shunt admittance per unit length
of the line.

Modal analysis is used to simplify the equations (2-8) and (2-9) above into a number of uncoupled sets of equations which can be solved conveniently. At this stage, it is assumed that the line is lossless.

The lossless line parameters are given by

$$[z] = \omega[L] = \omega \frac{\mu_0}{2\pi} [G] \quad (2-10)$$

$$[y] = \omega[C] = \omega 2\pi\epsilon_0 [G]^{-1} \quad (2-11)$$

where: $[L]$ is the inductance matrix of the line,
 $[C]$ is the capacitance matrix of the line,

μ_0 is the permeability of air,

ϵ_0 is the permittivity of air.

Equation (2-4) in Step 2 can be rewritten as

$$[J] = \frac{1}{2\pi\epsilon_0} [C][\Gamma] = [G]^{-1}[\Gamma] \quad (2-12)$$

Substituting equations (2-10) to (2-12) into equations (2-8) and (2-9) yield

$$\frac{d}{dx} [V] = - \frac{\omega\mu_0}{2\pi} [G][I] \quad (2-13)$$

$$\frac{d}{dx} [I] = - \omega 2\pi\epsilon_0 [G]^{-1}[V] + [G]^{-1}[\Gamma] \quad (2-14)$$

Let the modal matrix of $[G]$ be $[M]$ and $[\lambda]_d$ be the diagonal spectral matrix of $[G]$, then

$$[M]^{-1}[G][M] = [\lambda]_d \quad (2-15)$$

or

$$[G][M] = [\lambda]_d[M] \quad (2-16)$$

or

$$\{[G] - [\lambda]_d\}[M] = 0 \quad (2-17)$$

The equation (2-17) above has a non-trivial solutions only if the determinant of $\{[G] - [\lambda]_d\}$ is zero. Solving this characteristic equation of $[G]$ yields the eigenvalues λ_1 , λ_2 and λ_3 . Substituting these back into equation (2-17) will yield corresponding eigenvectors. Normalized column eigenvectors will form the modal transformation matrix $[M]$.

Step 5. Determination of modal components of corona current densities in the conductors

Let:

$$[V] = [M][V_c] \quad (2-18)$$

$$[I] = [M][I_c] \quad (2-19)$$

$$[J] = [M][J_c] \quad (2-20)$$

$$[\Gamma] = [M][\Gamma_c] \quad (2-21)$$

where V_c , I_c and J_c are the modal components of the voltage and currents and Γ_c is the modal components of the RI excitation function. Substituting equations (2-18) to (2-21) into equations (2-13) and (2-14) yield

$$\frac{d}{dx} [M][V_c] = - \frac{\omega\mu_0}{2} [G][M][I_c] \quad (2-22)$$

$$\frac{d}{dx} [M][I_c] = - \omega 2\pi\epsilon_0 [G]^{-1} [M][V_c] + [G]^{-1} [M][\Gamma_c] \quad (2-23)$$

Since RI is a direct result of the induced corona currents in the conductors, only the second part of equation (2-23) will be a matter of interest. The modal components of induced corona currents J_c are therefore obtained by the relationship

$$[J_c] = [M]^{-1} [G]^{-1} [M][\Gamma_c] \quad (2-24)$$

or

$$[J_c] = [M]^{-1} [G]^{-1} [\Gamma] \quad (2-25)$$

With the known values of the elements of matrices $[M]$ and $[G]$ and the excitation function for each phase, the values of the modal components of corona currents for each phase can be determined.

Step 6. Determination of corresponding modal components of the currents in the conductors

At this point, the effect of losses will be introduced in the form of modal attenuation factor α which is a function of frequency and ground resistivity. Required values of the attenuation factor can be obtained by using the empirical equation⁸

$$\alpha^m(f, \rho) = (f^{0.8} \sqrt{\frac{\rho}{100}}) \alpha^m(1.0, 100) \quad (2-26)$$

where: m is the mode number,

f is the frequency in Megahertz,

ρ is the ground resistivity in Ohm m

From the EPRI Reference Book⁸, the values of $\alpha^m(1.0, 100)$ are reproduced in Table 2.1 shown below.

Voltage class (kV)	Attenuation Constants		
	$\alpha^1(m^{-1})$	$\alpha^2(m^{-1})$	$\alpha^3(m^{-1})$
362	8.0×10^{-6}	60.0×10^{-6}	350.0×10^{-6}
550	9.3×10^{-6}	70.0×10^{-6}	350.0×10^{-6}
800	10.0×10^{-6}	70.0×10^{-6}	350.0×10^{-6}
1200	10.6×10^{-6}	84.0×10^{-6}	350.0×10^{-6}
1500	10.6×10^{-6}	84.0×10^{-6}	350.0×10^{-6}

Table 2.1 Modal attenuation constants for AC powerlines at 1 MHz with ground resistivity being 100 Ohm-m.

Under heavy rain conditions, the value of ρ is assumed to be 75.00 Ohm-m. Values of the modal components of the currents in the conductors are determined by the equation⁵

$$[I_c^m] = \frac{J_c^m}{2 \sqrt{\alpha^m}} \quad (2-27)$$

Step 7. Determination of the corresponding phase currents

Referring to equation (2-19) in Step 5, it can be rewritten as

$$[I] = [M][I_c^m] \quad (2-28)$$

or it can be expanded to become

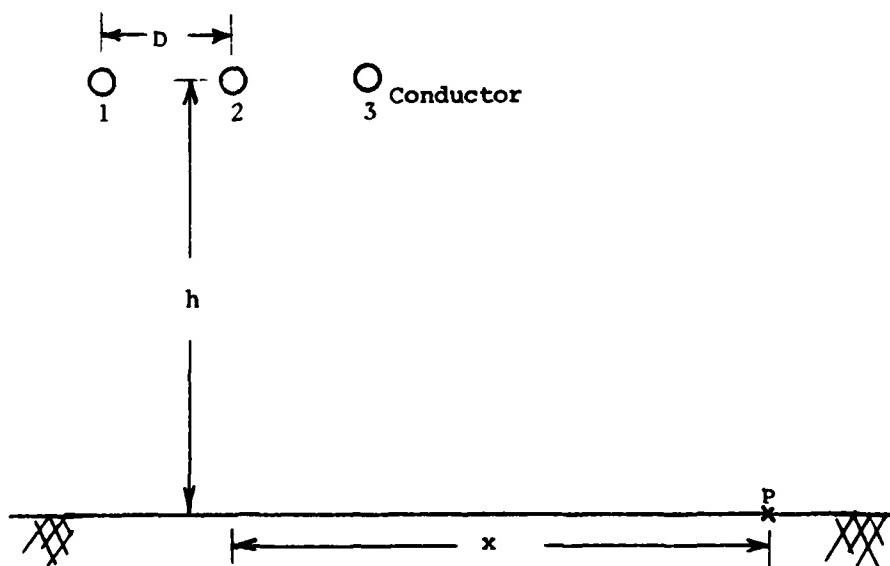


Fig. 2.1 Position of the observer at point P with respect to the AC powerlines for the calculation of RI noise.

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix} \begin{bmatrix} I_c^1 \\ I_c^2 \\ I_c^3 \end{bmatrix} \quad (2.29)$$

Equation (2-29) indicates that each modal current component I_c^m flows in all the three phases. For example, modal current I_c^2 will result in current $M_{12}I_c^2$ flowing in conductor 1, $M_{22}I_c^2$ in conductor 2 and $M_{32}I_c^2$ in conductor 3. The current components in the three conductors of any given mode are in phase with each other. However, the currents corresponding to different modes are not in phase due to different velocities of propagation.

Step 8. Determination of the RI noise field strength with the location of the observer at ground level

With the known values of the corona currents in each phase computed above, the resulting magnetic field and electric field can be conveniently calculated. Let the position of the observer be at P as illustrated in Fig. 2.1. The magnetic field strength at this location with respect to the center phase will be

$$H = \frac{I}{2\pi} \cdot \frac{2h}{h^2 + x^2} \quad (2-30)$$

Assuming a TEM mode of wave propagation, the corresponding electric field strength is obtained by the relationship of $E = Z_0 H$, where Z_0 is the wave impedance of free space. Since $Z_0 = 120\pi$, the electric field strength then is

$$E = 60 \cdot I \cdot \frac{2h}{h^2 + x^2} \quad (2-31)$$

where $60 \cdot \frac{2h}{h^2 + x^2}$ is termed as the field factor.

Let the field factors for conductors 1, 2 and 3 be $F_1(x)$, $F_2(x)$ and $F_3(x)$ respectively. Referring to Fig. 2.1 and equation (2-31), the field factors for respective conductors will be

$$F_1(x) = \frac{120h}{h^2 + (x+D)^2} \quad (2-32)$$

$$F_2(x) = \frac{120h}{h^2 + x^2} \quad (2-33)$$

$$F_3(x) = \frac{120h}{h^2 + (x-D)^2} \quad (2-34)$$

Using the above equations (2-32) to (2-34), the electric field strength at any point P due to corona for each mode can be obtained by

$$E_m = F_1(x) \cdot I_1^m + F_2(x) \cdot I_2^m + F_3(x) \cdot I_3^m \quad (2-35)$$

where m is the mode number 1, 2 or 3. The total electric field strength for each phase is calculated from

$$E_{ph} = \sqrt{E_{m=1}^2 + E_{m=2}^2 + E_{m=3}^2} \quad (2-36)$$

Finally, the resultant electric field strength, therefore RI noise, due to corona currents on all the phases at any point P is

$$E = \sqrt{E_{ph=1}^2 + E_{ph=2}^2 + E_{ph=3}^2} \quad (2-37)$$

where E is in $\mu V/m$, or it can be converted into dB above 1 $\mu V/m$.

Appendix A outlines the derivation for equations of field factors for point P anywhere in space and Appendix C details the Program ACRI listings for the computation of RI noise level from AC powerlines.

The RI noise level computed here is for 1 kHz receiver bandwidth. In general, a bandwidth correction factor of $10 \log b(\text{dB})$, where b is the receiver bandwidth, is added to the result obtained in equation (2-37). This form is applicable throughout this report. Table 2.2 lists typical values of bandwidth correction factors.

b (kHz)	$10 \log b(\text{dB})$
1	0.00
2	3.01
3	4.77
4	6.02
5	6.99

Table 2.2 Typical values of bandwidth correction factor

For illustration, some actual line designs are considered. Table 2.3 lists the line voltages and parameters and Fig. 2.2 show the line configurations

Line Config.	Line Voltage (kV)	H (m)	D (m)	d_c (cm)	n	A (cm)
# 1	345	13.61	8.31	3.038	2	45.70
# 2	500	14.43	12.19	2.959	3	52.80
# 3	765	20.83	13.72	2.959	4	64.70
# 4	1100	21.34	15.24	3.556	8	101.60

Table 2.3 AC line voltages and parameters considered

where H is the average height of the conductors,

D is the spacing between the conductors,

d_c is the diameter of the subconductors,

n is the number of subconductors in a bundle,

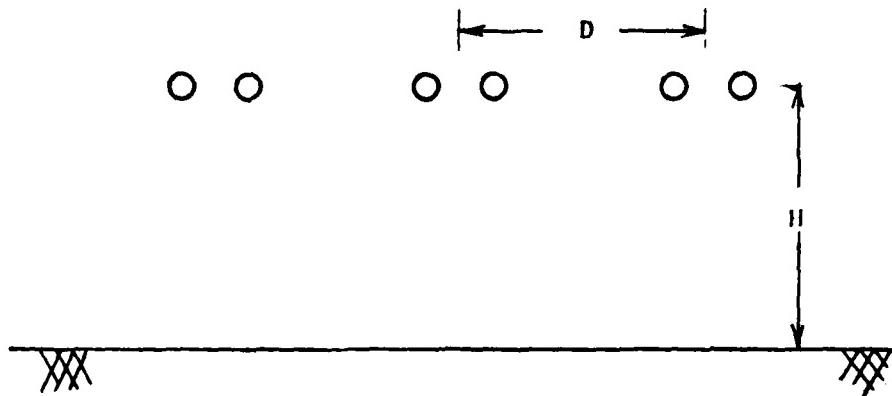


Fig. 2.2a Line configuration #1 for 345 KV

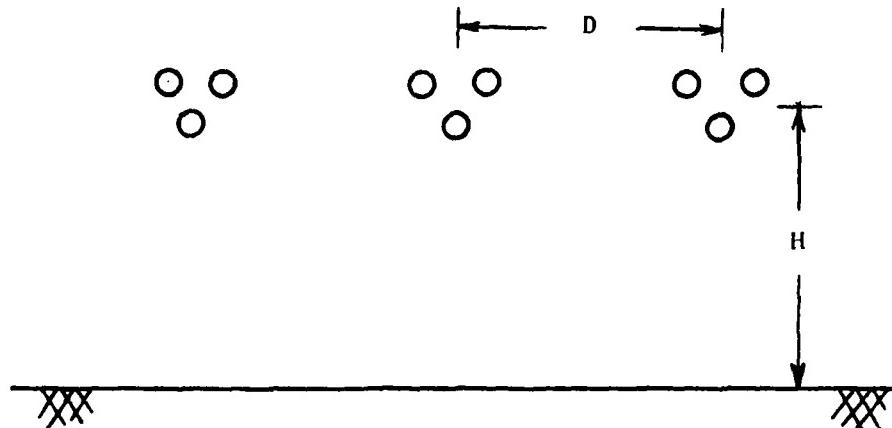


Fig. 2.2b Line configuration #2 for 500 KV

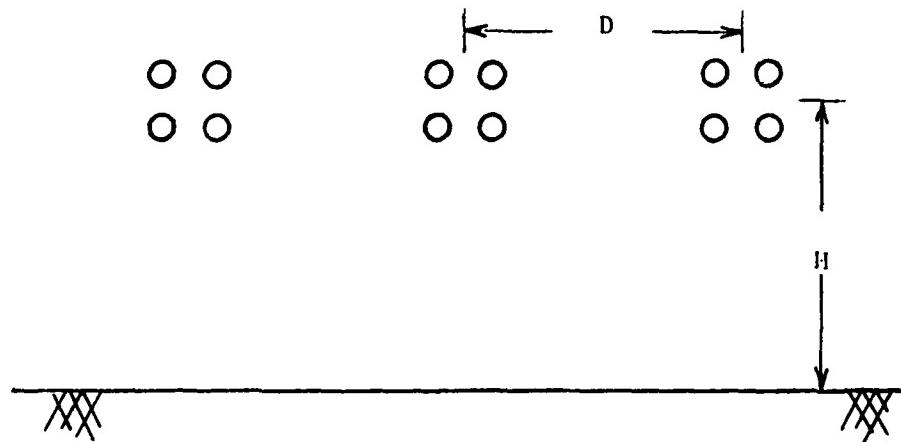


Fig. 2.2c Line configuration #3 for 765 KV

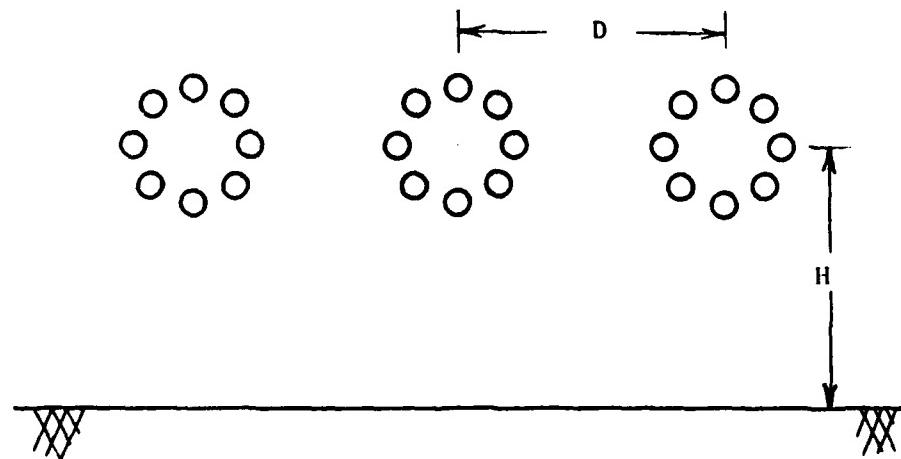


Fig. 2.2d Line configuration #4 for 1100 KV

Λ is the diameter of a bundle.

By using the modal analysis method detailed above, the RI noise level is calculated for each of the line designs listed in Table 2.3 at frequencies of 200 kHz and 500 kHz with the observer at various altitudes. Fig. 2.3 to 2.6 illustrate the characteristics of the calculated RI noise levels radiated from the AC powerlines.

2.3 Computation of Signal Strength from an NDB Transmitter

Based on the assumptions that the heights of the transmitting and receiving antenna are within a few wavelengths of the earth's surface and that they are separated by a short distance such that the curvature of the earth is negligible, a flat earth model can be used for the computation of the electric field strength of the signal from an NDB transmitter.

An initial approximate computation assumes that the earth is infinitely conducting. Later, this result is modified by multiplication by the flat earth attenuation function developed by Wait⁹, which will give the final result of the electric field strength over a finitely conducting earth. Fig. 2.7 illustrates a vertical electric monopole of length " ℓ " carrying current I located on the surface of a finitely conducting earth.

Harrington¹⁰ states that far from a current element in free space, the electric field strength is given by

$$E_\theta = \eta \frac{jI\ell}{2\lambda r} \cdot e^{-jkr} \cdot \sin \theta \quad (2-38)$$

and the actual average power radiated by the current element is

$$P_r = \eta \frac{2\pi}{3} \cdot \left| \frac{I\ell}{\lambda} \right|^2 \quad (2.39)$$

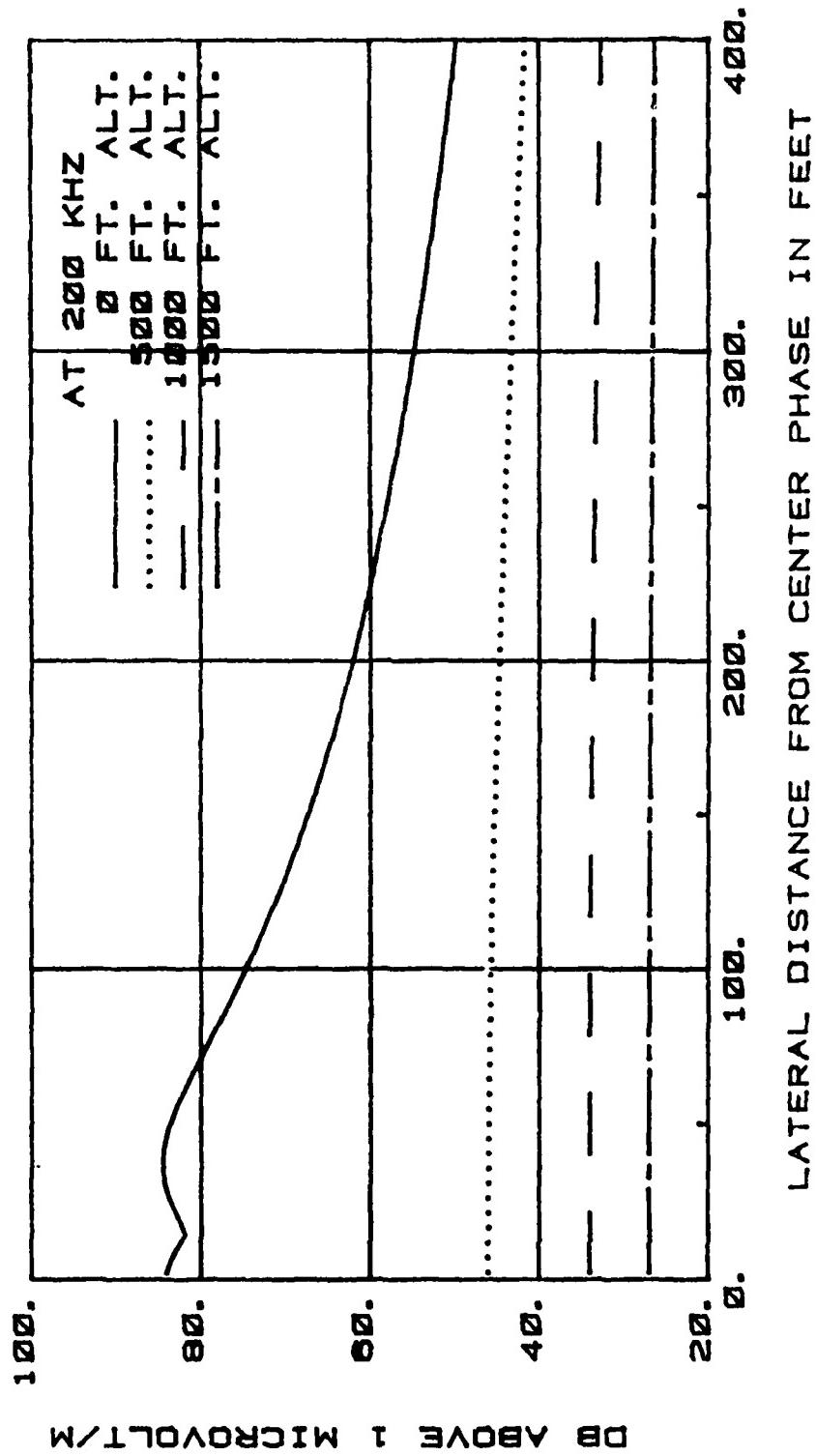


Fig. 2.3a Calculated RI noise profile for 345 kV AC powerline at 200 kHz under heavy rain condition

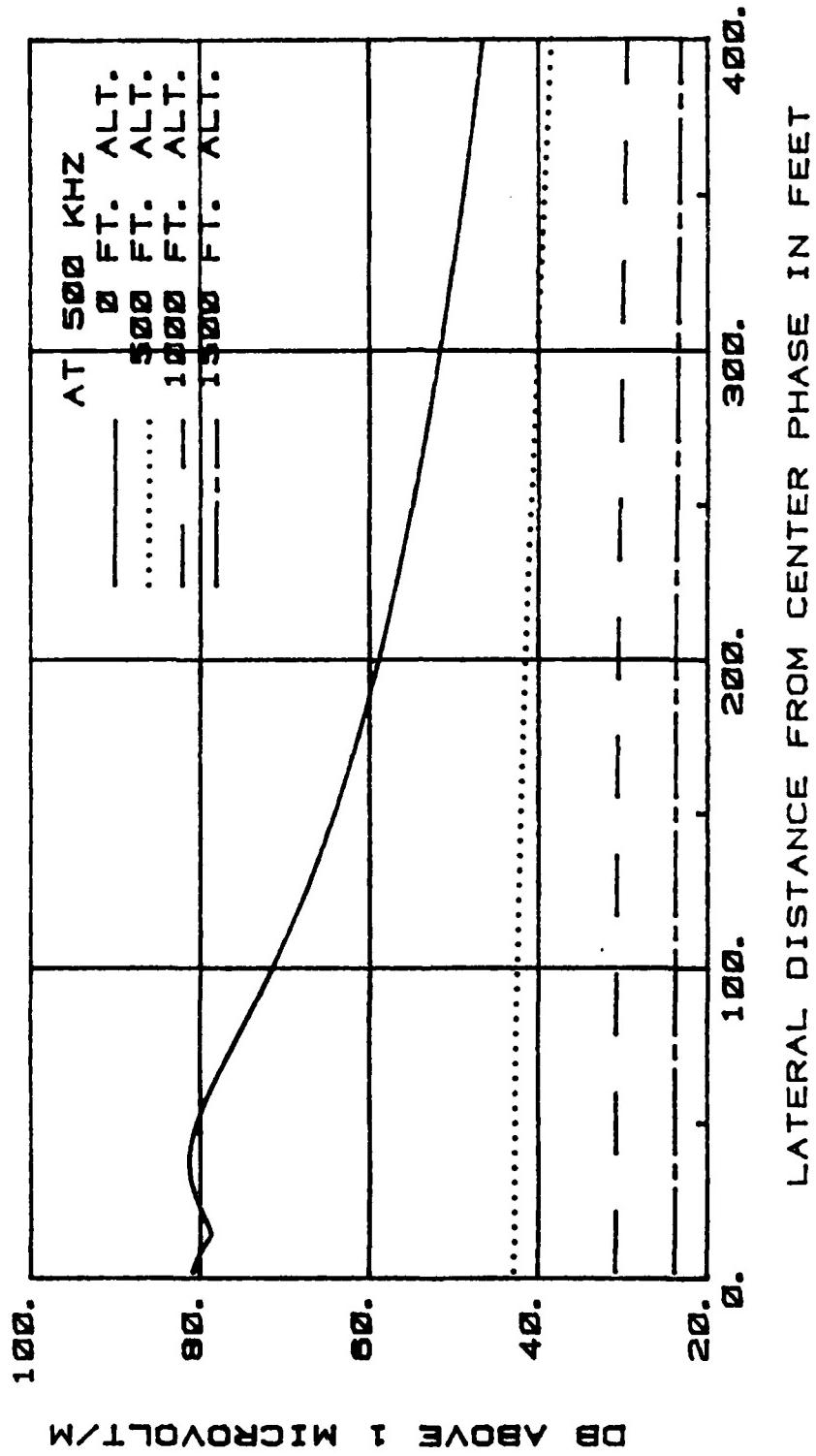


Fig. 2.3b Calculated RI noise profile for 345 kV AC powerline at 500 kHz under heavy rain condition

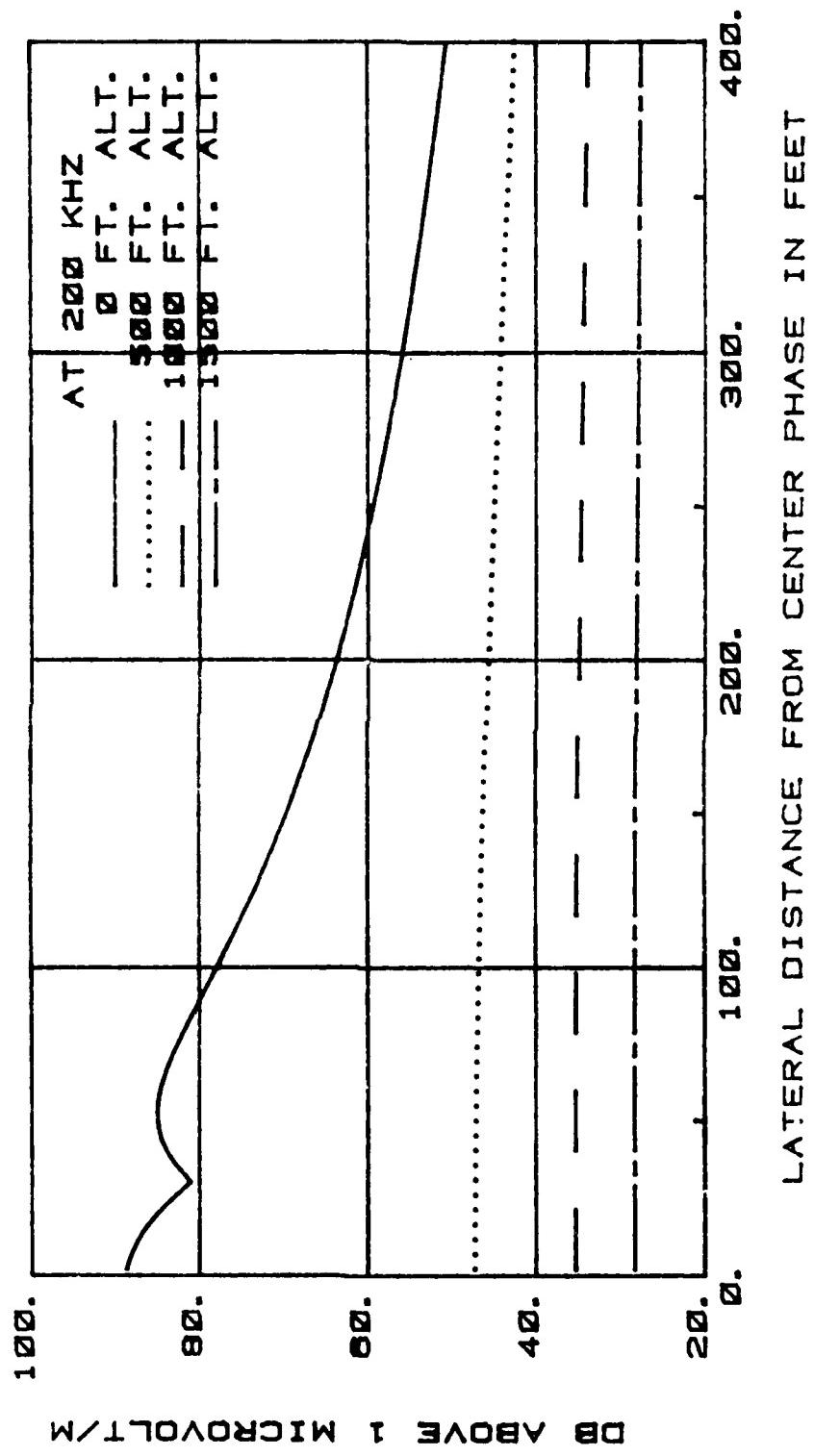
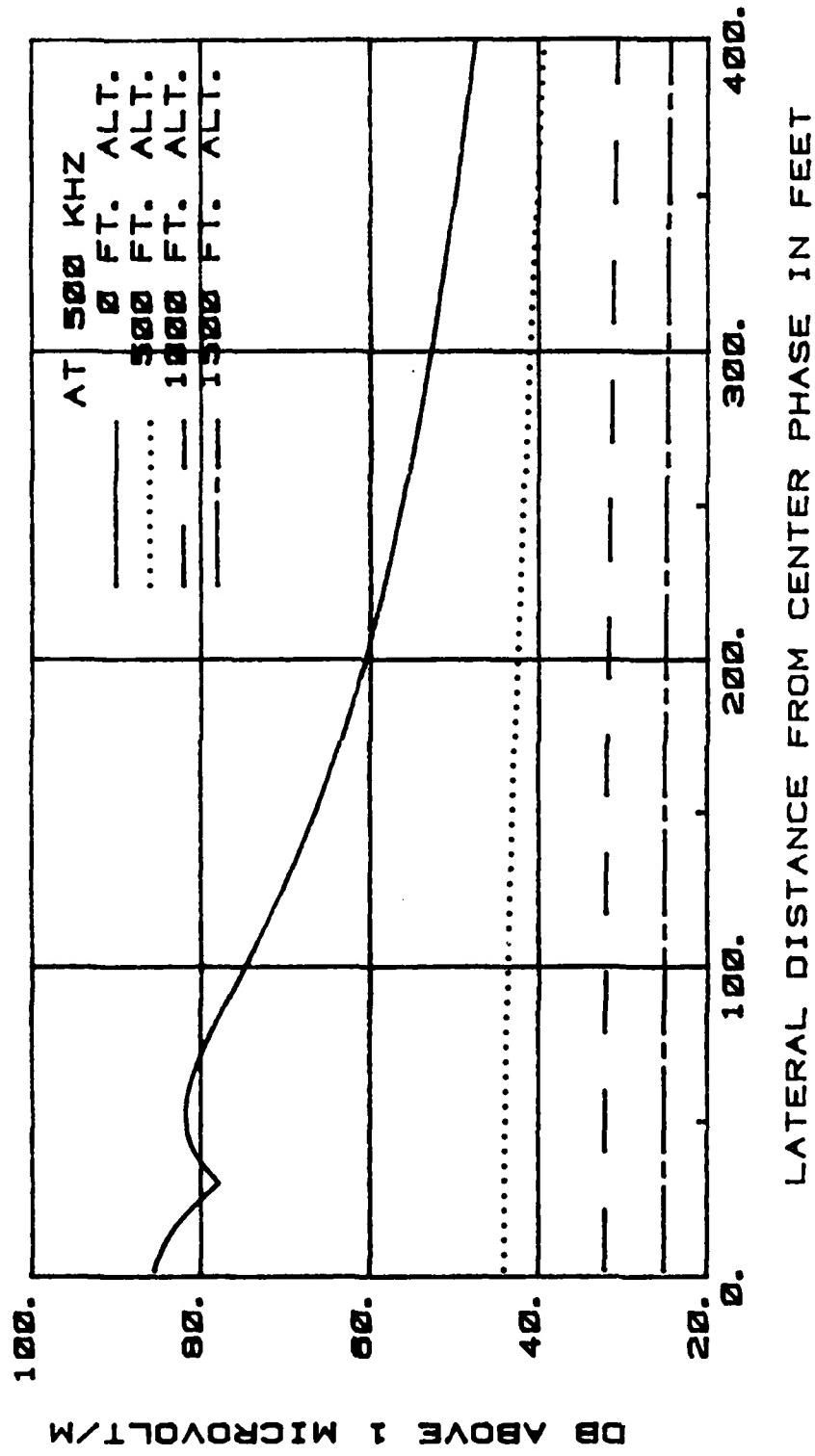


Fig. 2.4a Calculated RI noise profile for 500 kV AC powerline at 200 kHz under heavy rain condition



LATERAL DISTANCE FROM CENTER PHASE IN FEET

Fig. 2.4b Calculated RI noise profile for 500 kV AC powerline at 500 kHz
under heavy rain condition

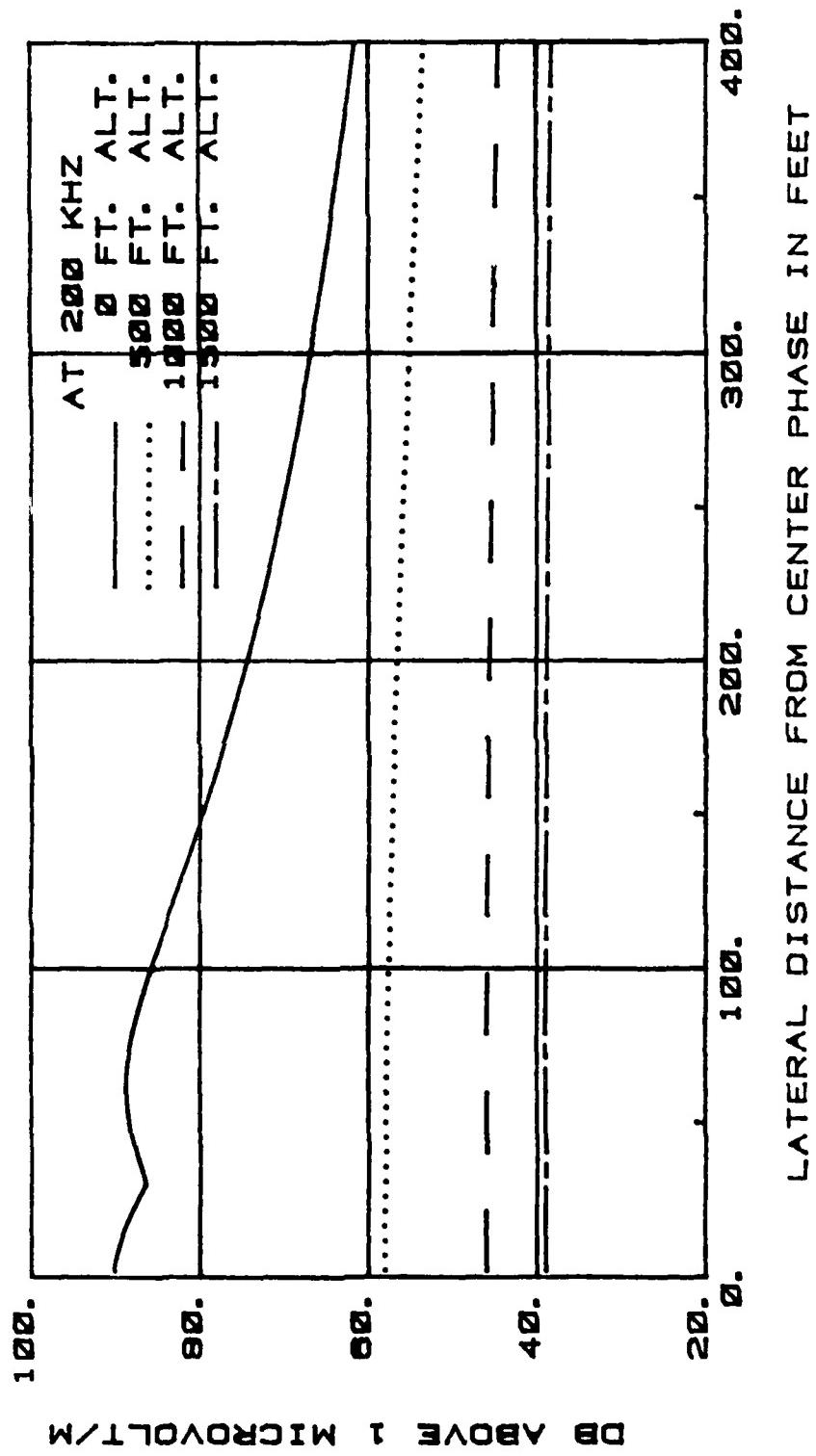


Fig. 2.5a Calculated RI noise profile for 765 kV AC powerline at 200 kHz under heavy rain condition

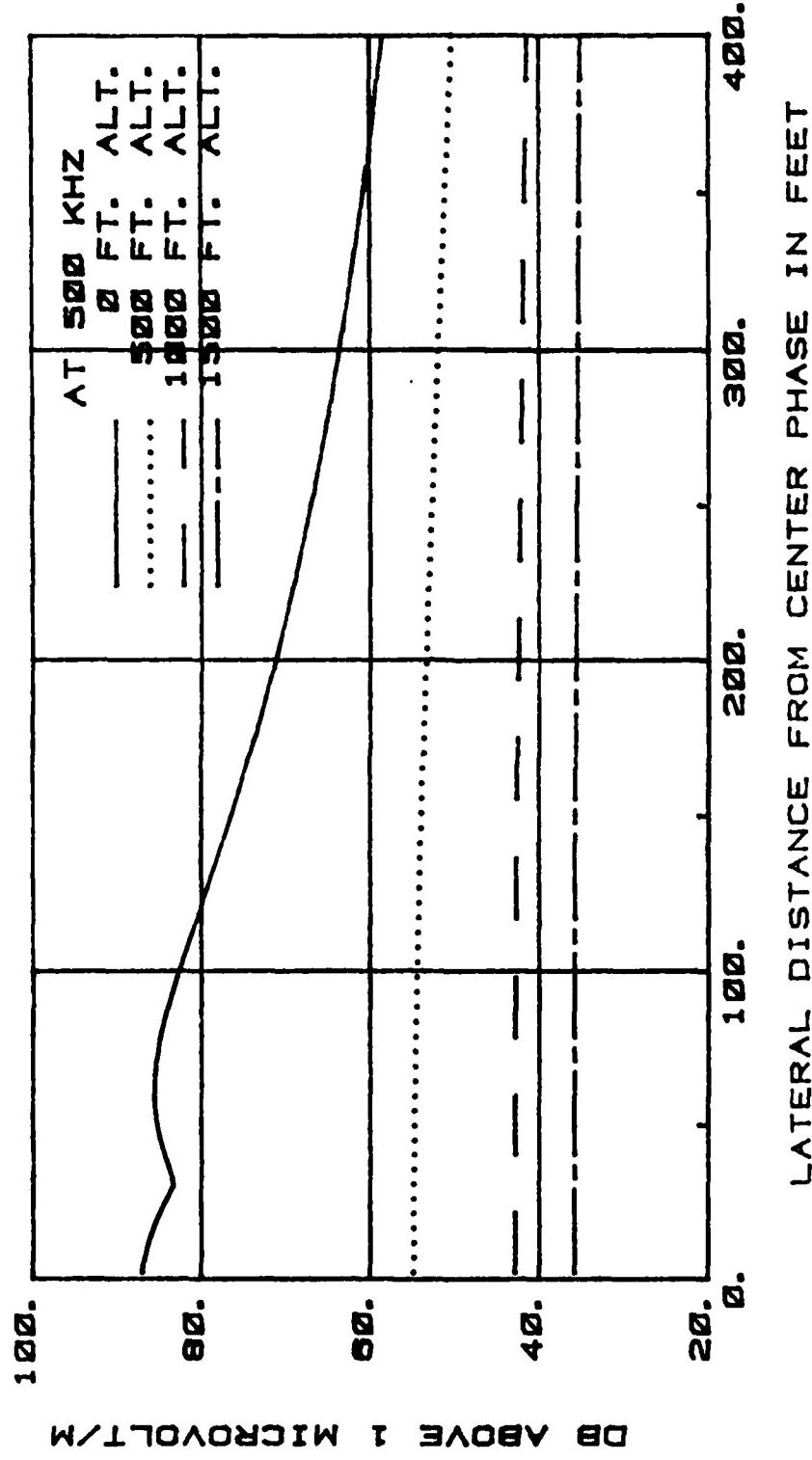


Fig. 2.5b Calculated RI noise profile for 765 kV AC powerline at 500 kHz under heavy rain condition

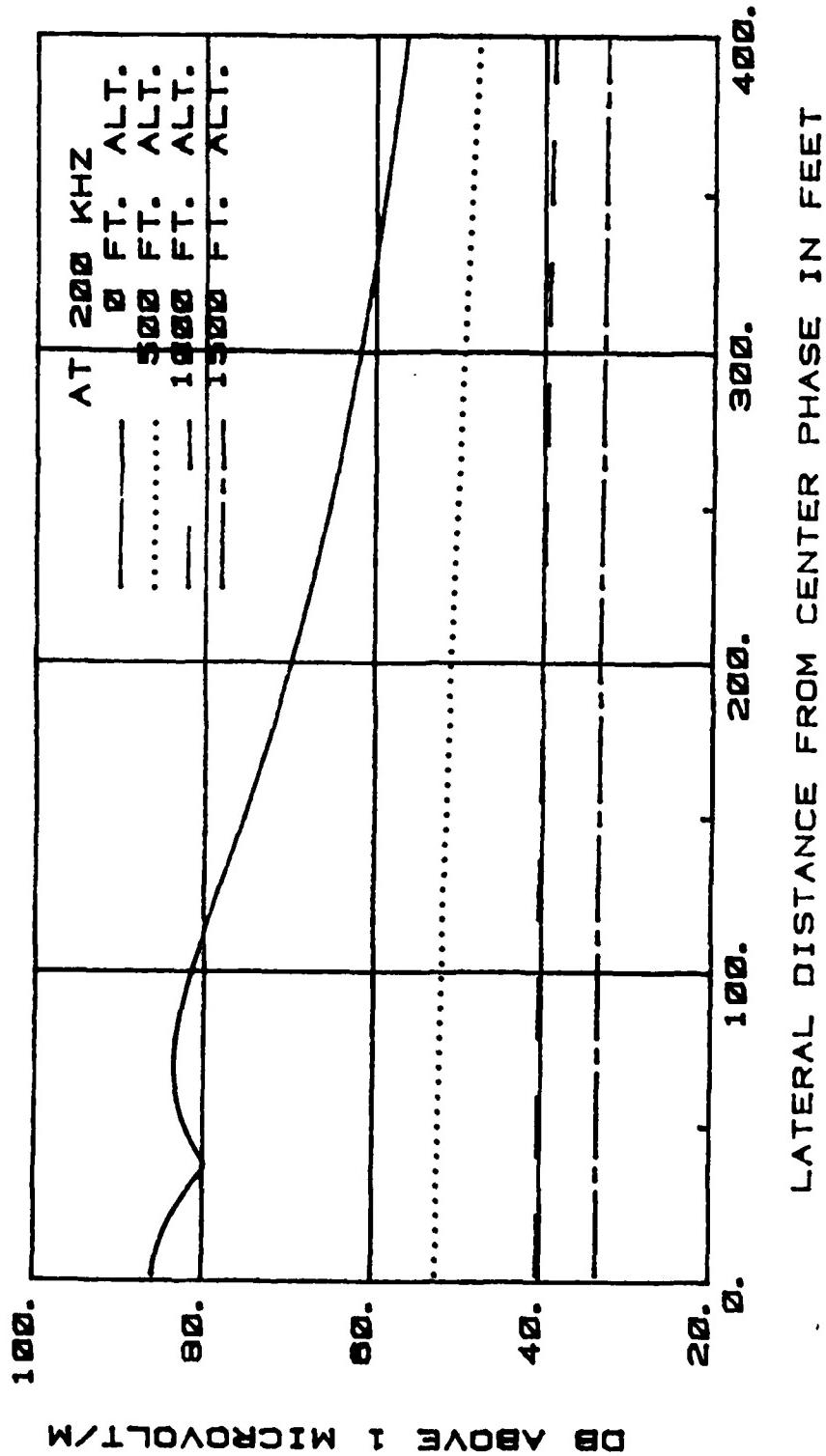


Fig. 2.6a Calculated RI noise profile for 1100 kV AC powerline at 200 kHz under heavy rain condition.

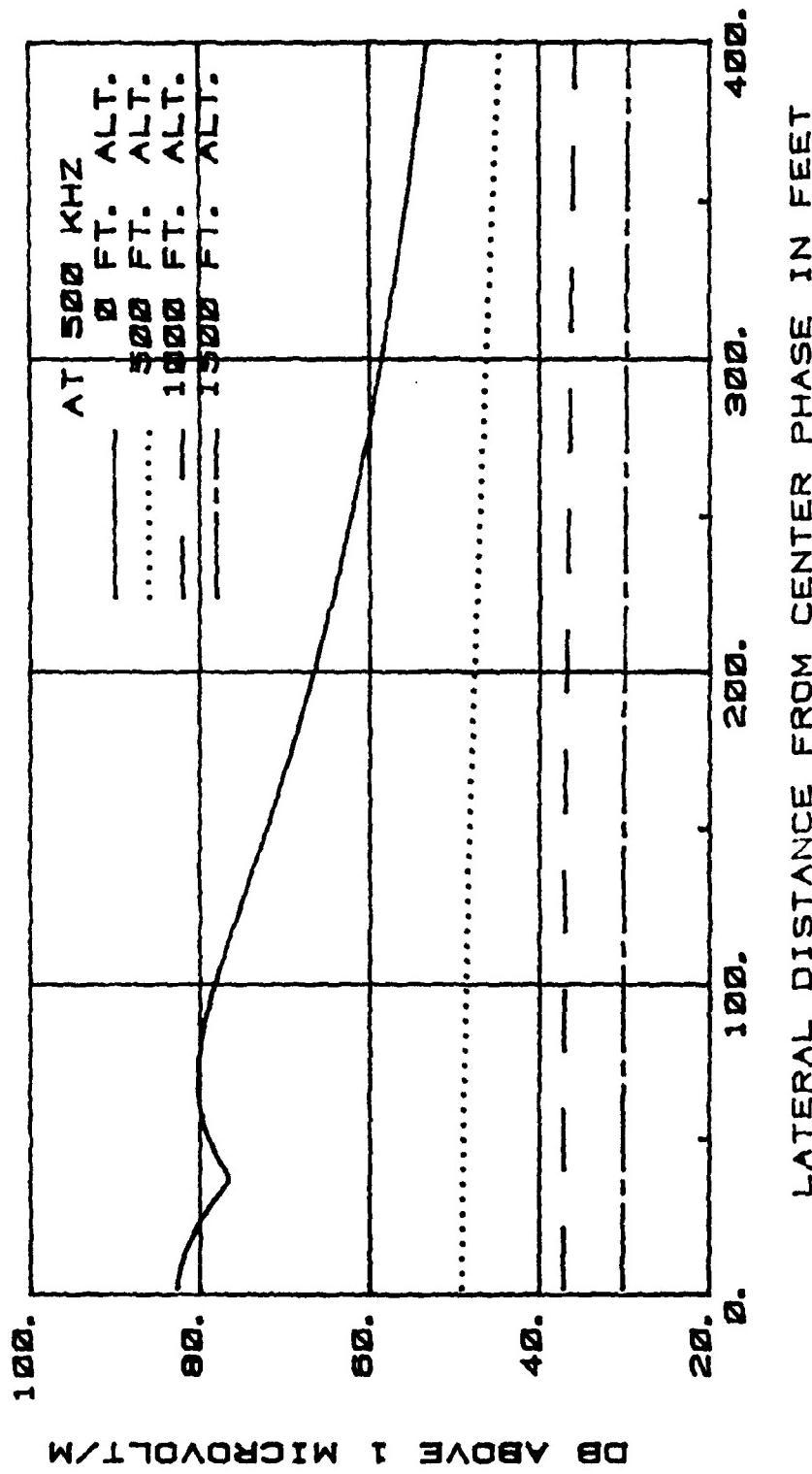


Fig. 2.6b Calculated RI noise profile for 1100 kV AC powerline at 500 kHz under heavy rain condition.

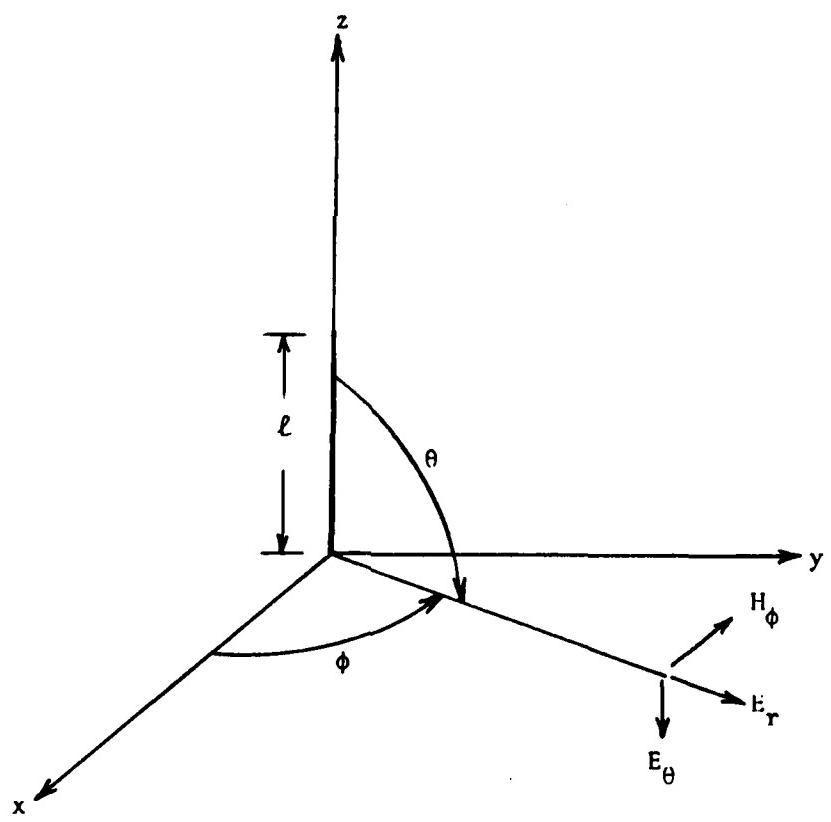


Fig. 2.7 Geometry of flat earth model

where: η is the wave impedance of free space,

λ is the wavelength,

k is the wave constant

r is the distance from the transmitting antenna.

Since we are interested only in the magnitude of the electric field strength near the ground, equation (2-38) can be simplified into

$$E_0 = \eta \frac{I\ell}{2\lambda r} \quad (2-40)$$

If the earth is assumed to be present but infinitely conducting, due to image theory, the far field term will be exactly doubled. Therefore

$$E_0 = \eta \frac{I\ell}{\lambda r} \quad (2-41)$$

and the corresponding value of the actual average power radiated is given by

$$P_r = \eta \frac{4\pi}{3} \cdot \left| \frac{I\ell}{\lambda} \right|^2 \quad (2-42)$$

From equation (2-42) above,

$$I\ell = \lambda \sqrt{\frac{3P_r}{4\eta\pi}} \quad (2-43)$$

Substituting equation (2-43) into (2-41) yields

$$E_0 = \sqrt{\frac{3\eta}{4\pi}} \cdot \sqrt{\frac{P_r}{r}} = 9.487 \sqrt{\frac{P_r}{r}} \quad (2-44)$$

Finally, by multiplying equation (2-44) by the flat earth attenuation function, the resulting electric field strength over a finitely conducting earth is

$$E = \frac{9.487 \sqrt{\frac{P_r}{r}}}{r} (1.00 - R_o \delta c z^2 \operatorname{erfc}(z)) \quad (2-45)$$

where: E is the electric field strength in $\mu\text{V}/\text{m}$,

P_r is the effective radiated power in watts,

$$\delta = \sqrt{\frac{\eta - 1}{\eta}} \quad (2-46)$$

$$\text{and } \eta = \epsilon_r - j \frac{1.8 \times 10^7 \cdot \sigma}{f} \quad (2-47)$$

with ϵ_r and σ the relative permittivity and conductivity in mho/m of the earth respectively, f the frequency in kilohertz,

$$R_0 = e^{j\pi/4} \sqrt{\frac{\pi k D}{2}} \quad (2-48)$$

$$\text{and } D = \sqrt{r^2 + (h_1 - h_2)^2} \quad (2-49)$$

with $k = 2\pi/\lambda$, λ being the free space wavelength, and h_1 and h_2 the antenna heights; erfc is the complementary error function as defined by Abramowitz and Stegun¹¹ and

$$z = e^{j\pi/4} \cdot \sqrt{\frac{k D}{2}} \cdot \delta \cdot \left(1.00 + \frac{h_1 + h_2}{\delta D}\right) \quad (2-50)$$

Assuming that the transmitting antenna is a 40-foot high vertical radiator, the relative permittivity of earth is 10.0 and the ground conductivity be 10.0 mmho/m, Fig. 2.8 to 2.11 illustrate the patterns of the electric field strength for NDB transmitters with an effective radiated power (ERP) of 0.05 watt, 0.10 watt, 0.5 watts and 1.0 watt respectively, at the frequencies of 200 kHz and 500 kHz with the receiver altitude at ground level and at 1500 feet above ground. Appendix D details program signal listing for the computation of the electric field strength from an NDB for short distances under the above conditions.

2.4 Prediction of the Critical Distance Where the Ratio of Desired Signal/Uncertain Noise is 15 dB

The desired signal is the signal from the NDB transmitter and the

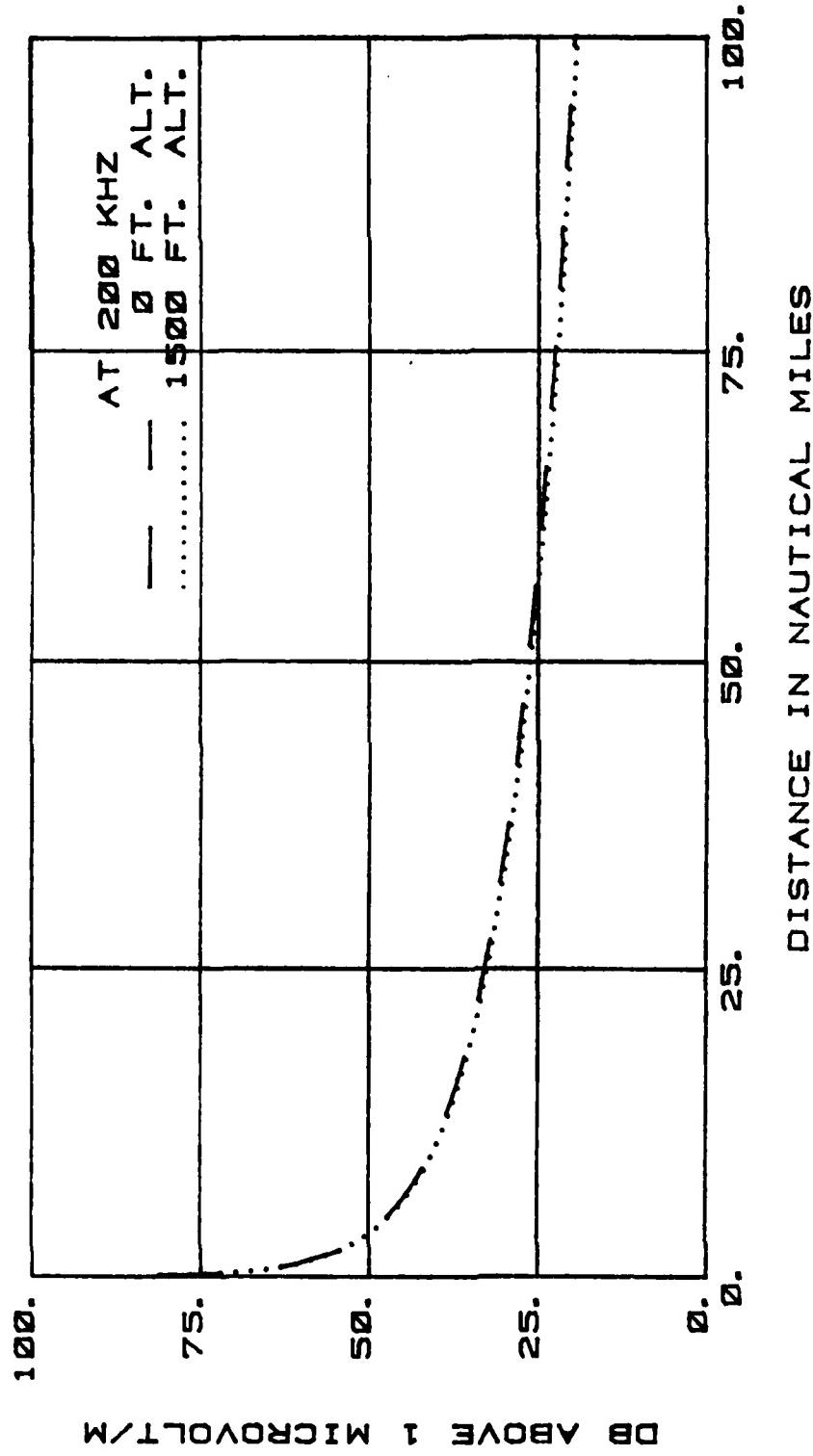


Fig. 2.8a Transmitter; ERP = 0.05 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0 \text{ mho/m}$,
 $f = 200 \text{ kHz}$.

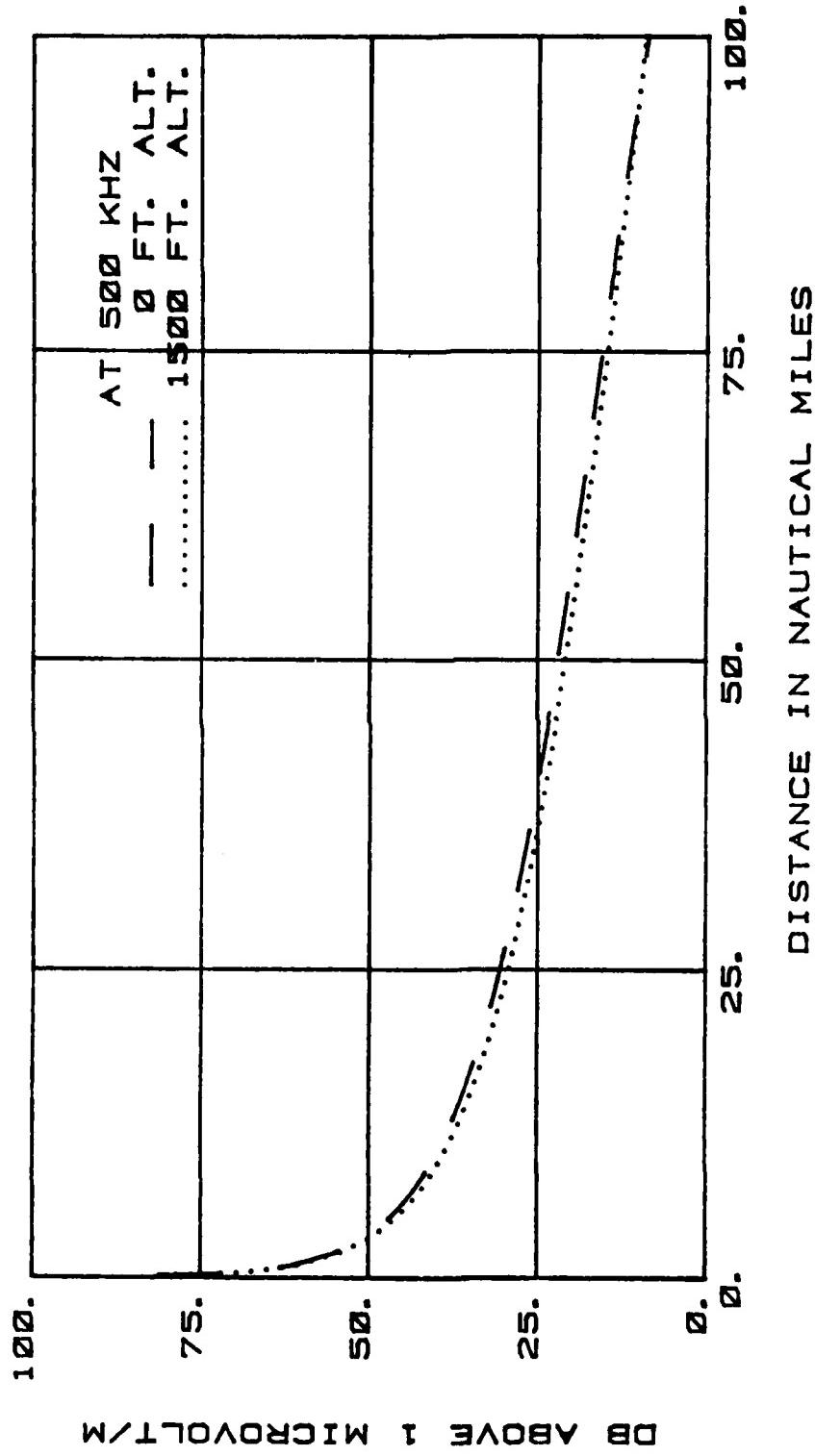


Fig. 2.8b Transmitter; ERP = 0.05 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0 \text{ mmho/m}$,
 $f = 500 \text{ kHz}$.

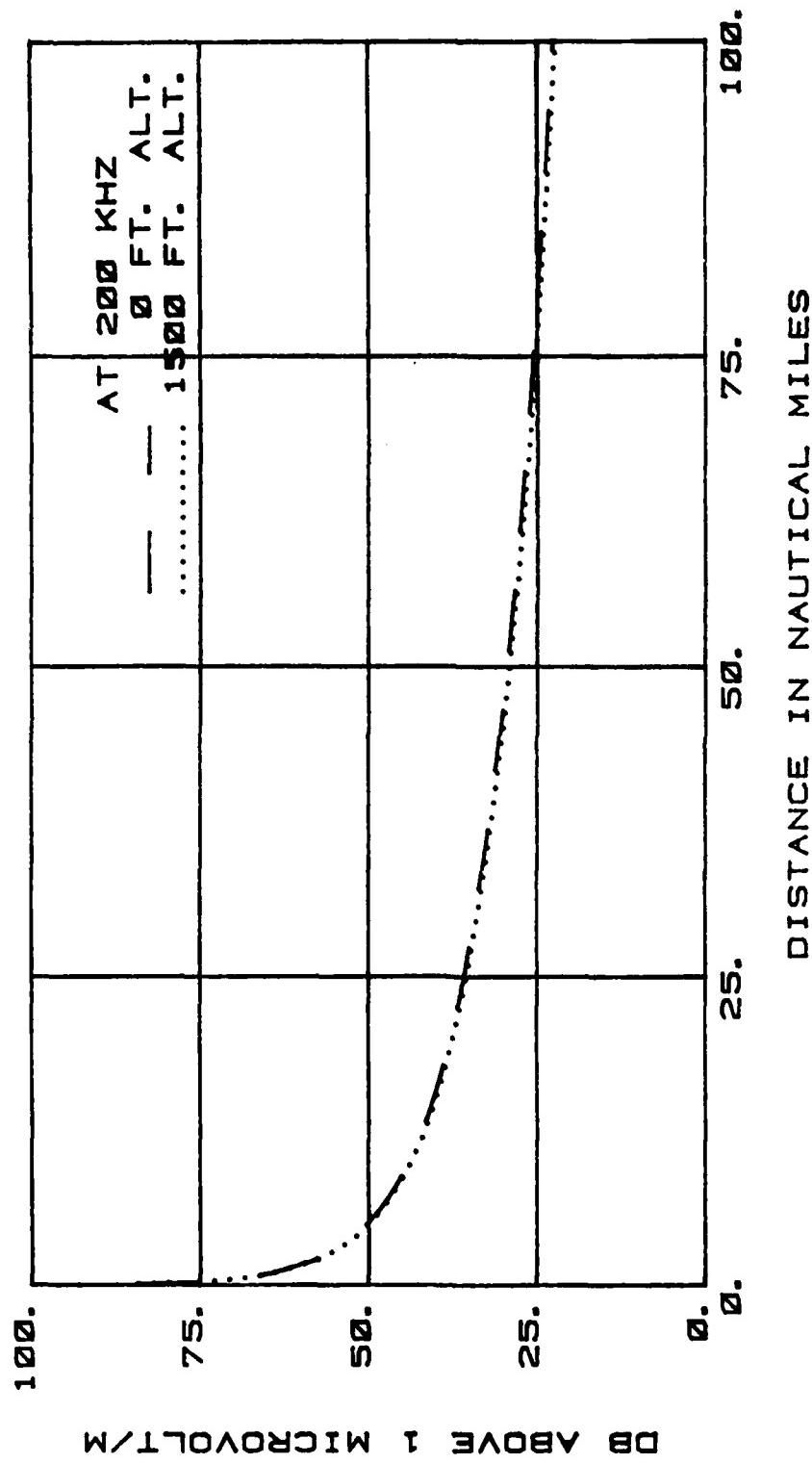


Fig. 2.9a Transmitter; ERP = 0.1 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0 \text{ mho/m}$, $f = 200 \text{ kHz}$.

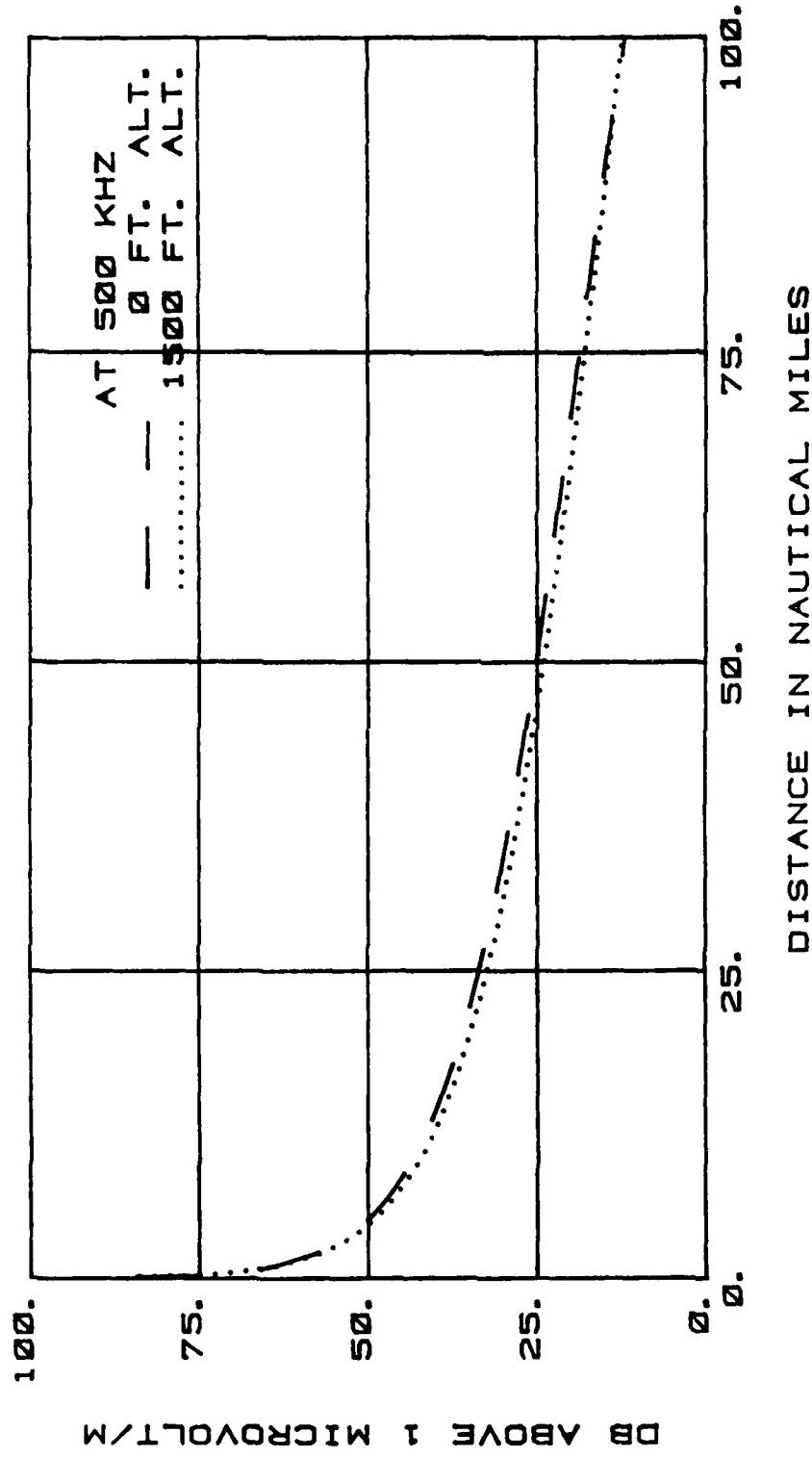


Fig. 2.9b Transmitter; ERP = 0.1 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0 \text{ mmho/m}$,
 $f = 500 \text{ kHz}$.

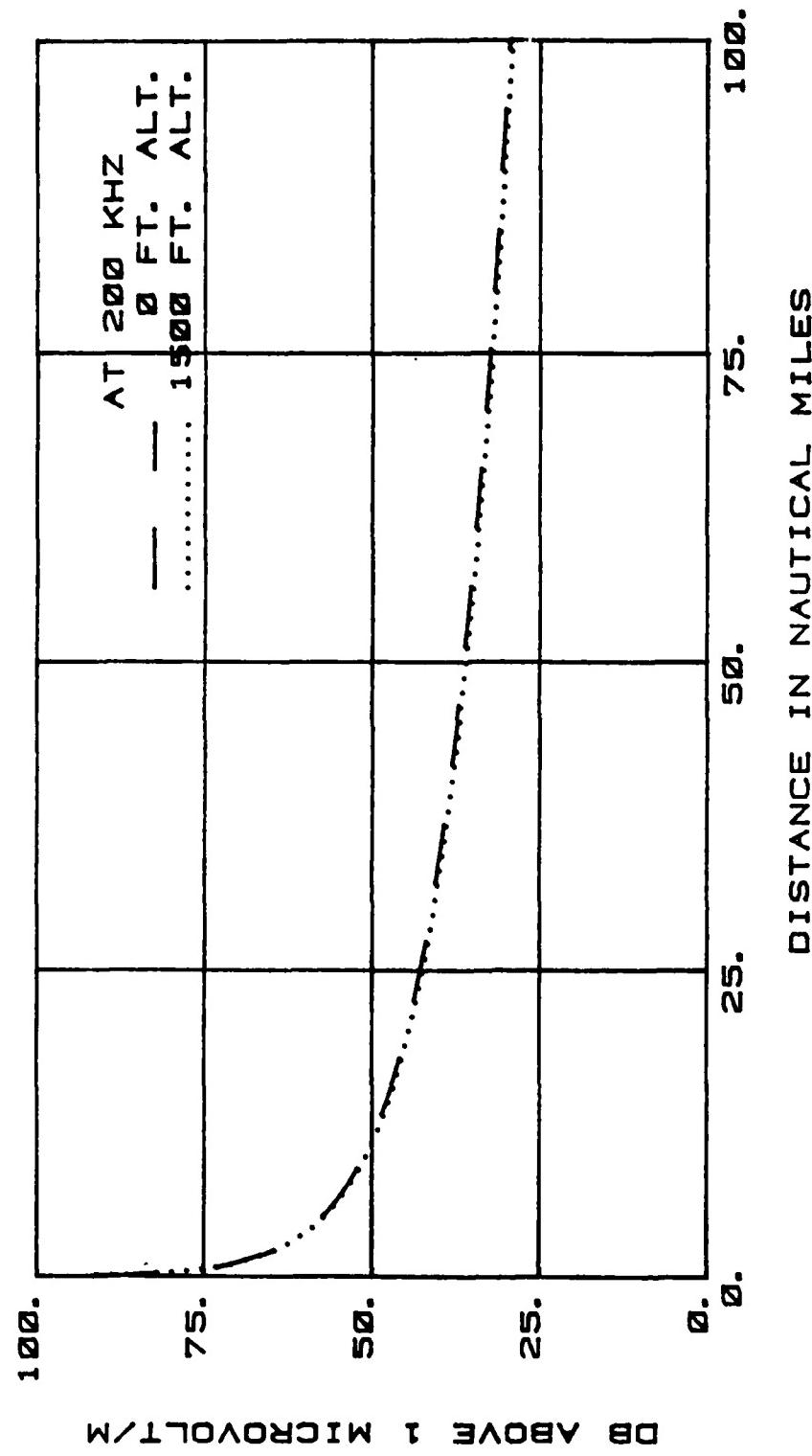


Fig. 2.10a Transmitter; ERP = 0.5 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0 \text{ mmho/m}$,
 $f = 200 \text{ kHz}$.

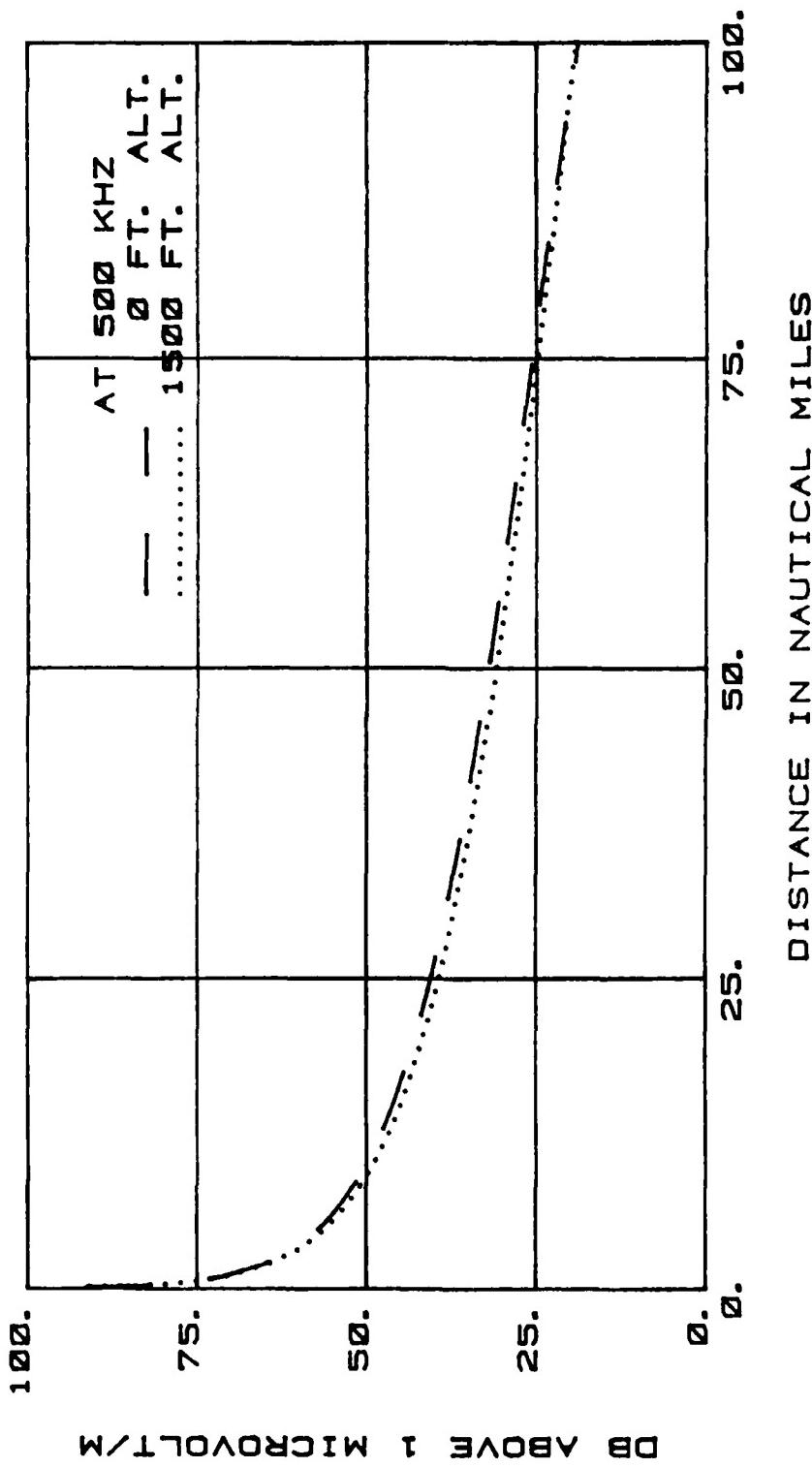


Fig. 2.10b Transmitter; ERP = 0.5 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0 \text{ mmho/m}$, $f = 500 \text{ kHz}$.

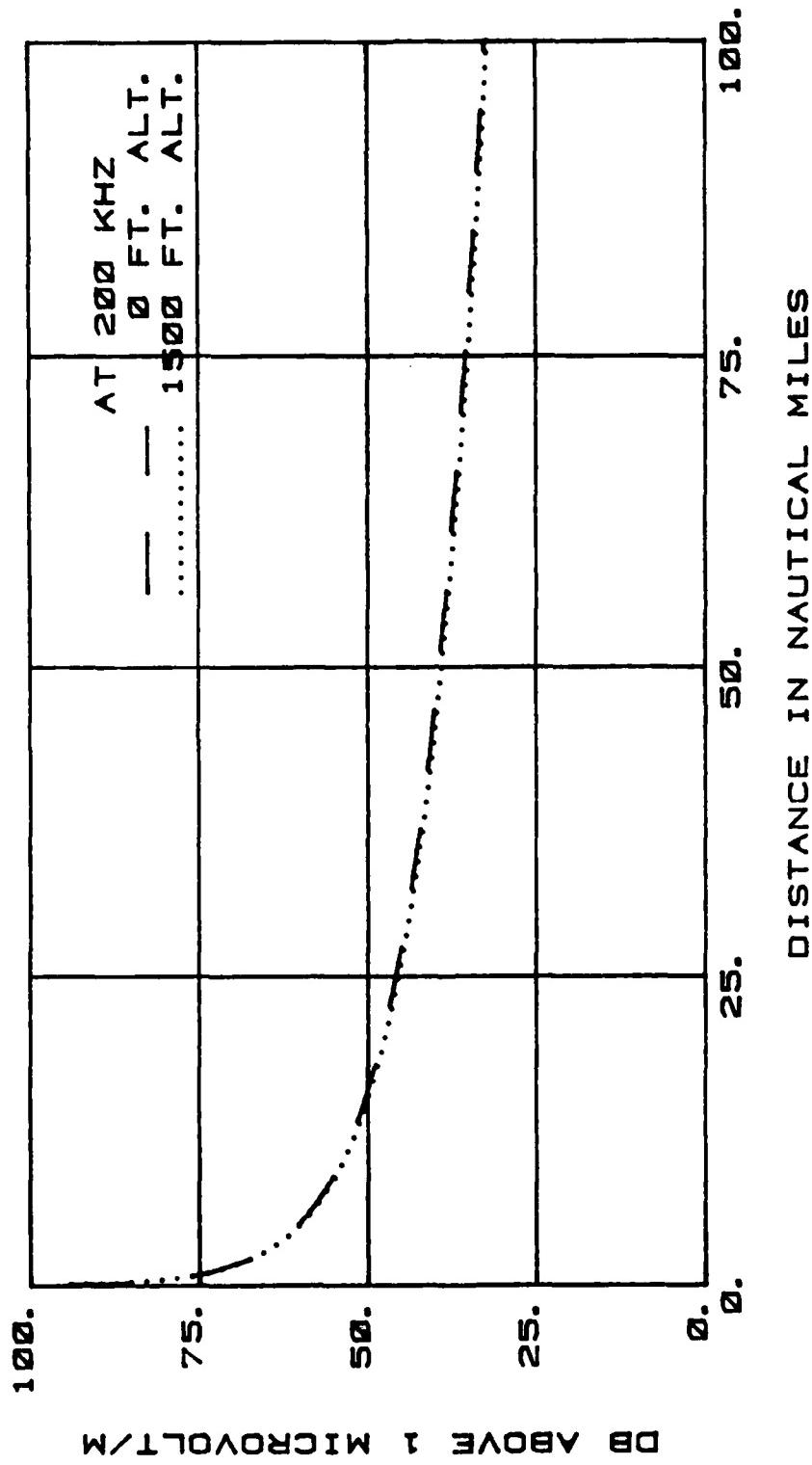


Fig. 2.11a Transmitter; ERP = 1.0 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0 \text{ mmho/m}$, $f = 200 \text{ kHz}$.

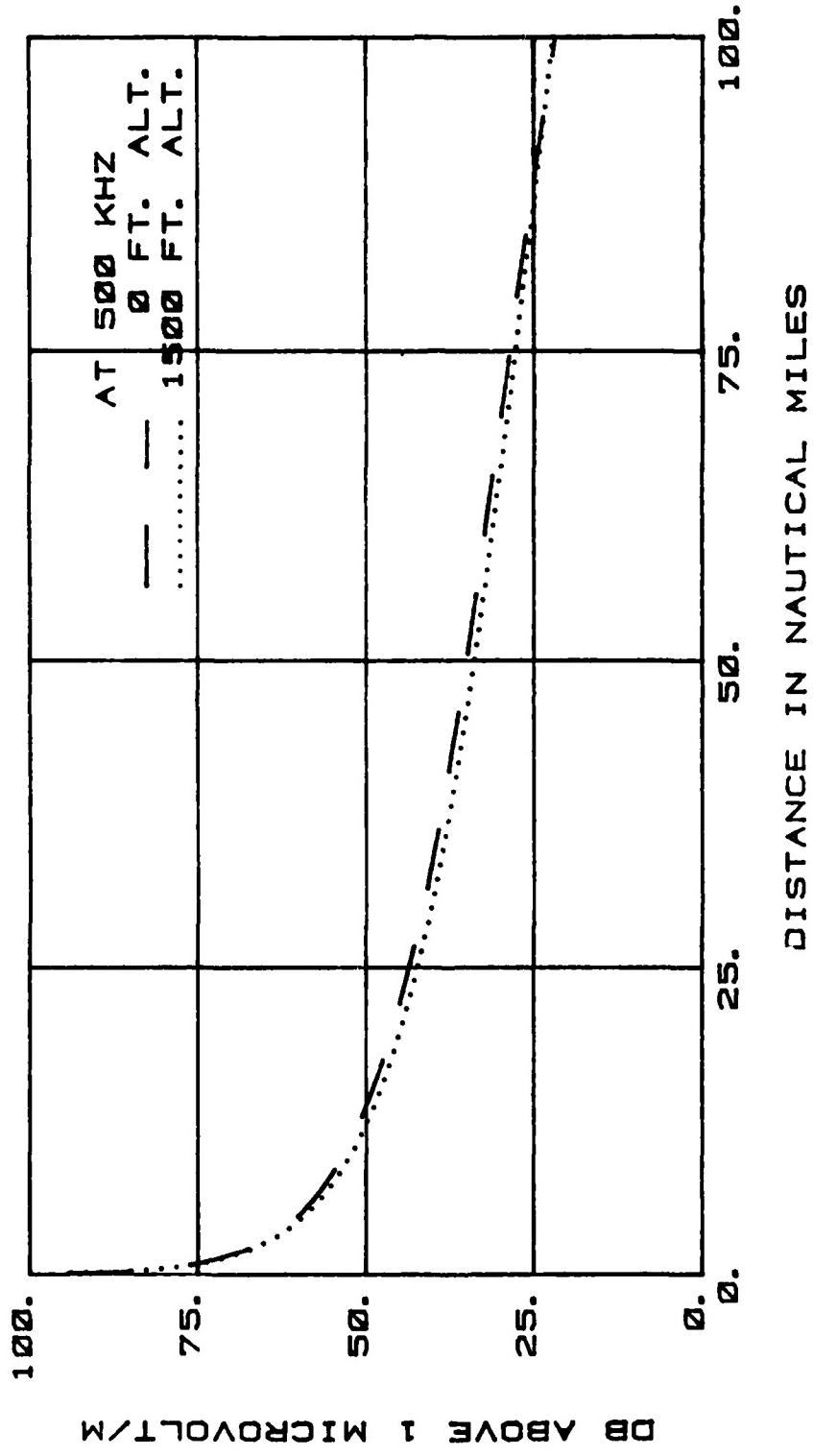


Fig. 2.11b Transmitter; ERP = 1.0 watt, $\epsilon_r = 10.0$, ground $\sigma = 10.0 \text{ mho/m}$, $f = 500 \text{ kHz}$.

undesired signal is the RI noise from the AC powerlines. The former has been dealt with in Section 2.3 and the latter in Section 2.2. Consider the scenario illustrated in Fig. 2.12. The scenario in question illustrates a worst case condition where the path of the aircraft flying over the powerline is perpendicular to it, the aircraft and the NDB transmitter are on the opposite side of the powerline and a heavy rain is falling. Let the distance separating the NDB transmitting antenna and the powerlines be y nautical miles, the lateral distance between the powerlines and the location of the receiver (aircraft) be x feet and let the receiver be at h feet above ground. For various line designs mentioned in Section 2.2 and different values of ERP of NDB transmitter covered in Section 2.3, Fig. 2.13 to 2.24 indicate the critical distance x feet where the ratio of the desired signal/undesired noise is 15 dB with the receiver at various altitudes.

For example, in Fig. 2.23a, where the ERP of the NDB is 1 watt and the line voltage is 765 kV, if the distance separating the NDB and the powerline is 10 NM, the critical distance for an aircraft flying at an altitude of 1500 feet is about 300 feet from the line.

After examination of Figures 2.13 to 2.24 it will be noticed that the critical distance, and thus the RI noise level, increases as line voltage is increased from 345 kV to 500 kV to 765 kV, but decreases as the voltage is further increased to 1100 kV. The reason for this is that the 1100 kV line considered has 8 subconductors, while the 765 kV line has only 4 (see Fig. 2.2, Table 2.3). This causes the maximum electric field for the 1100 kV line to be less than that for the 765 kV line, thus reducing the RI noise level.

2.5 Conclusion

At ground level, the radiated RI noise is vertically polarized. However, at any other location in space, the radiated RI noise is not entirely vertically polarized. In determining the critical distance, which involves the computation of desired signal/undesired noise ratio, no attempt is made to take the RI noise component aligned with the vertical direction. Instead, a worst case condition is considered in which only the magnitudes of both fields are taken into account.

In computing the RI noise from the powerlines, a quasi-static condition is assumed. This is valid if the wavelength of the frequency under consideration is large compared to powerline parameters (height and phase spacing) and to the distance between the powerlines and the measuring points. Thus, at any point too far from the lines, the validity of this assumption is questionable. However, for completeness, low ERP and large distances are being considered in this report.

Fig. 2.13 to 2.24 have indicated that for a range of low ERP and the line designs considered, if the location of the powerline is close to an NDB, the critical distance is small at any receiver altitudes. Thus it can be concluded that if a powerline is close to an NDB transmitter, the RI noise radiated by the powerline will practically cause no appreciable effect to an aircraft flying past it.

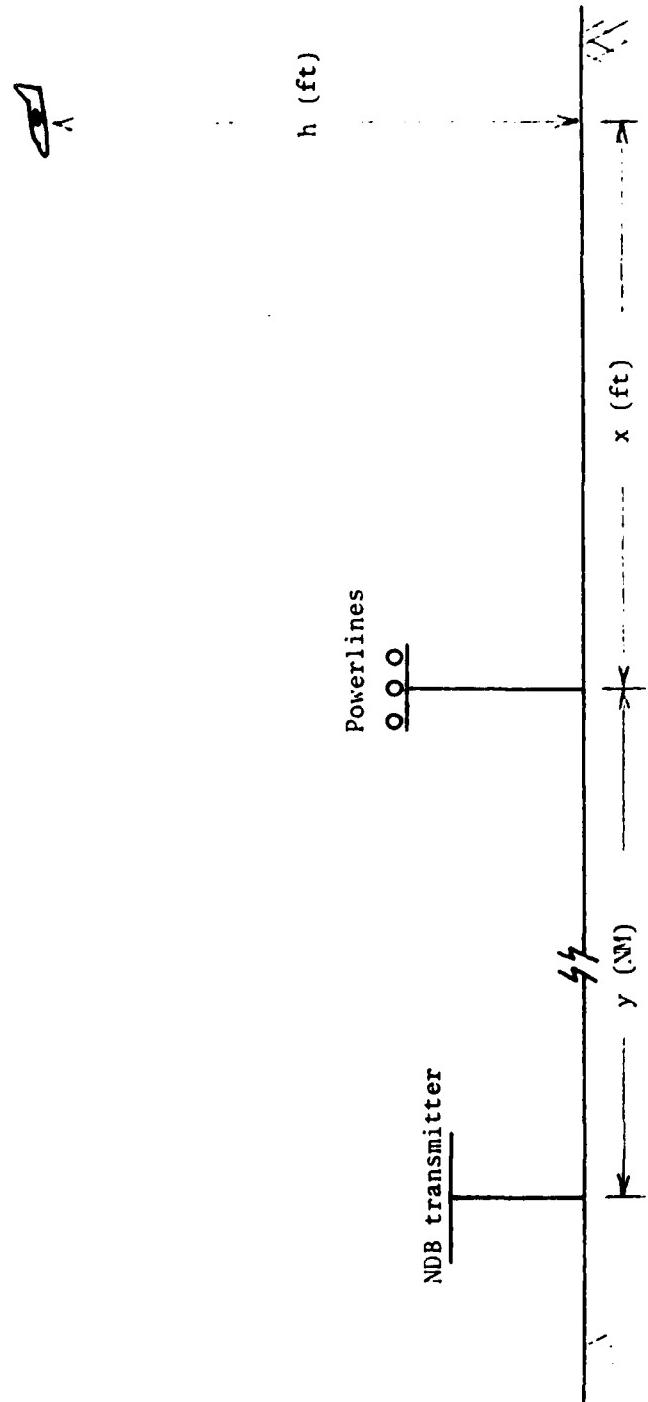
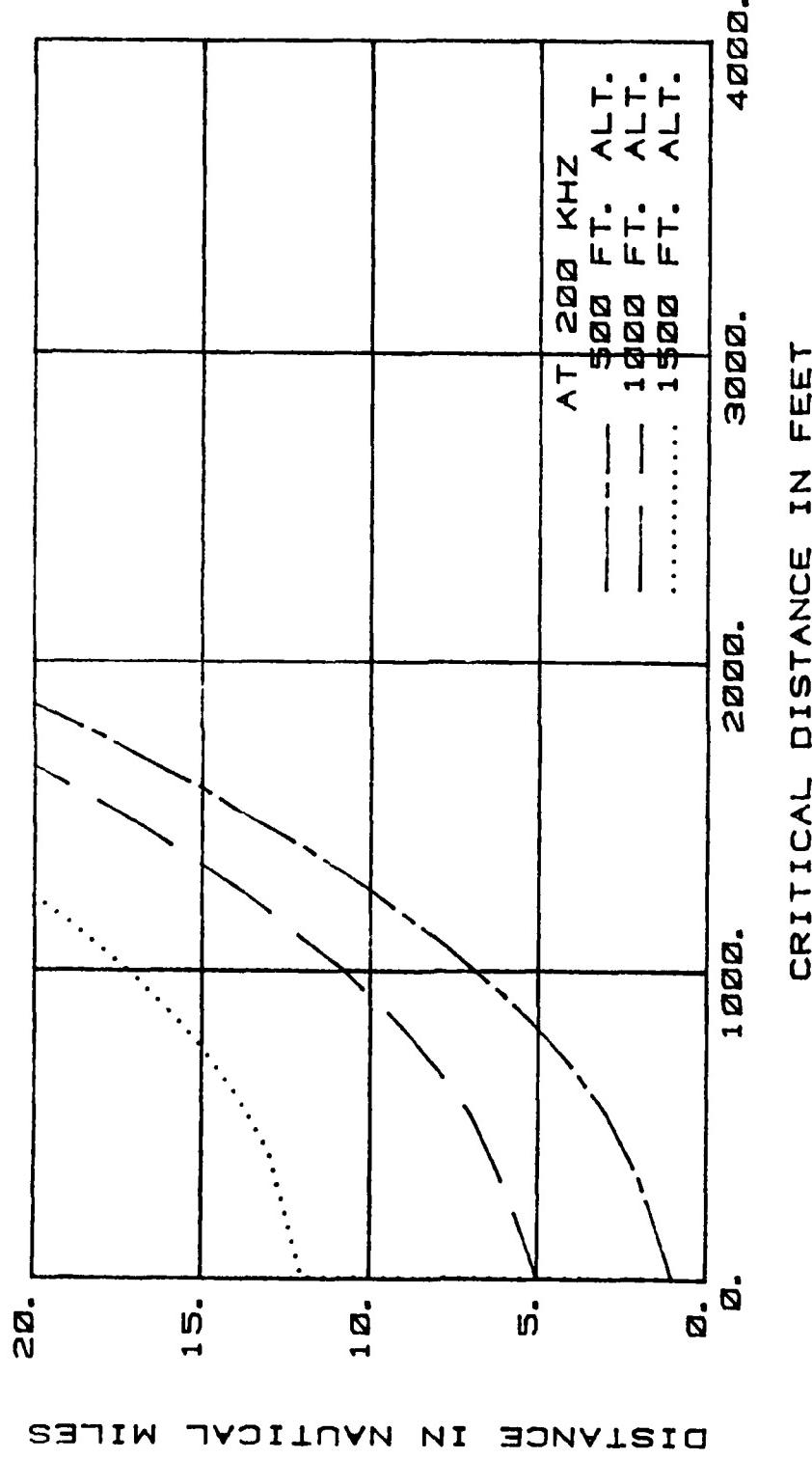
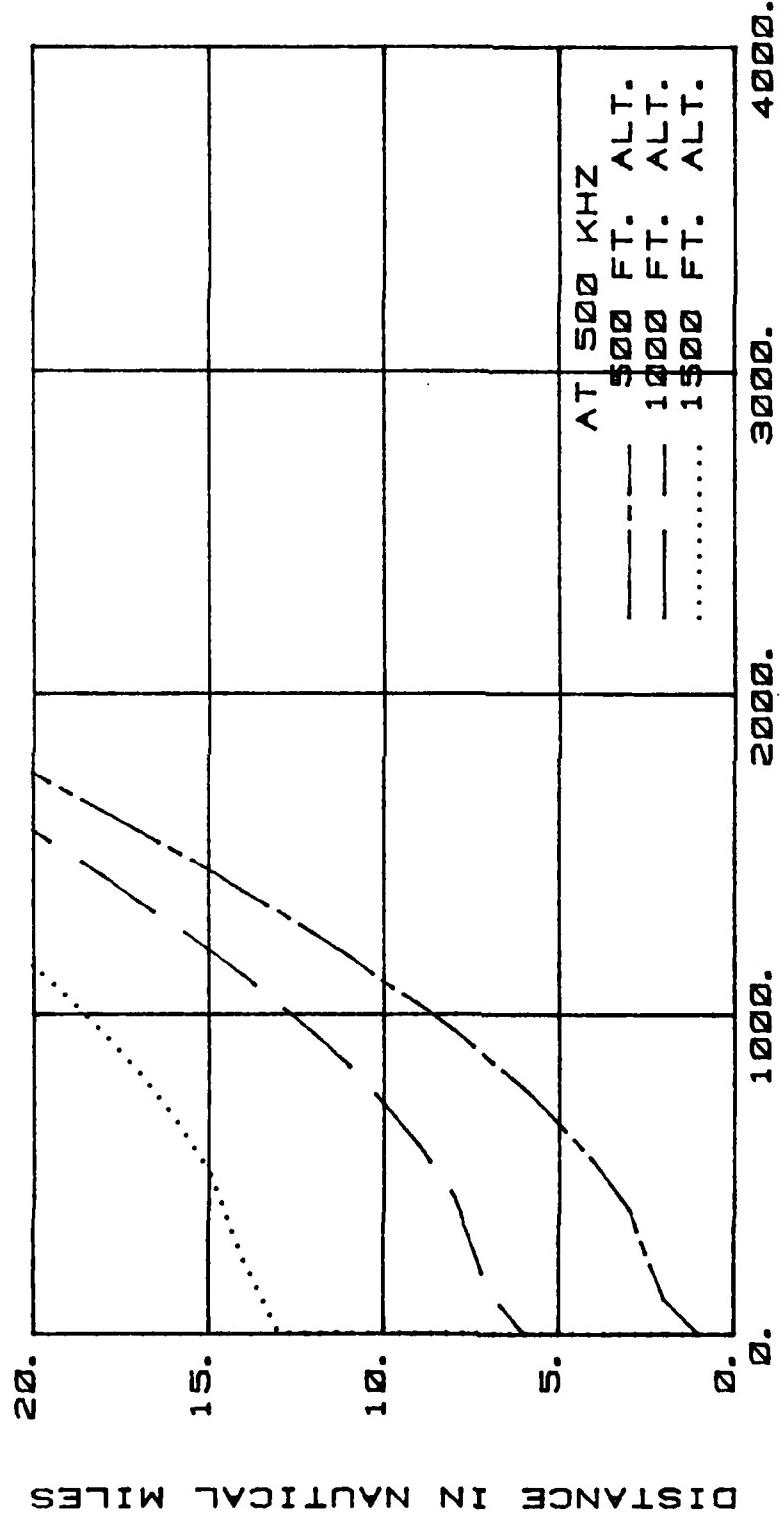


Fig. 2.12 A scenario of an aircraft flying over powerlines with an NDB transmitter nearby.



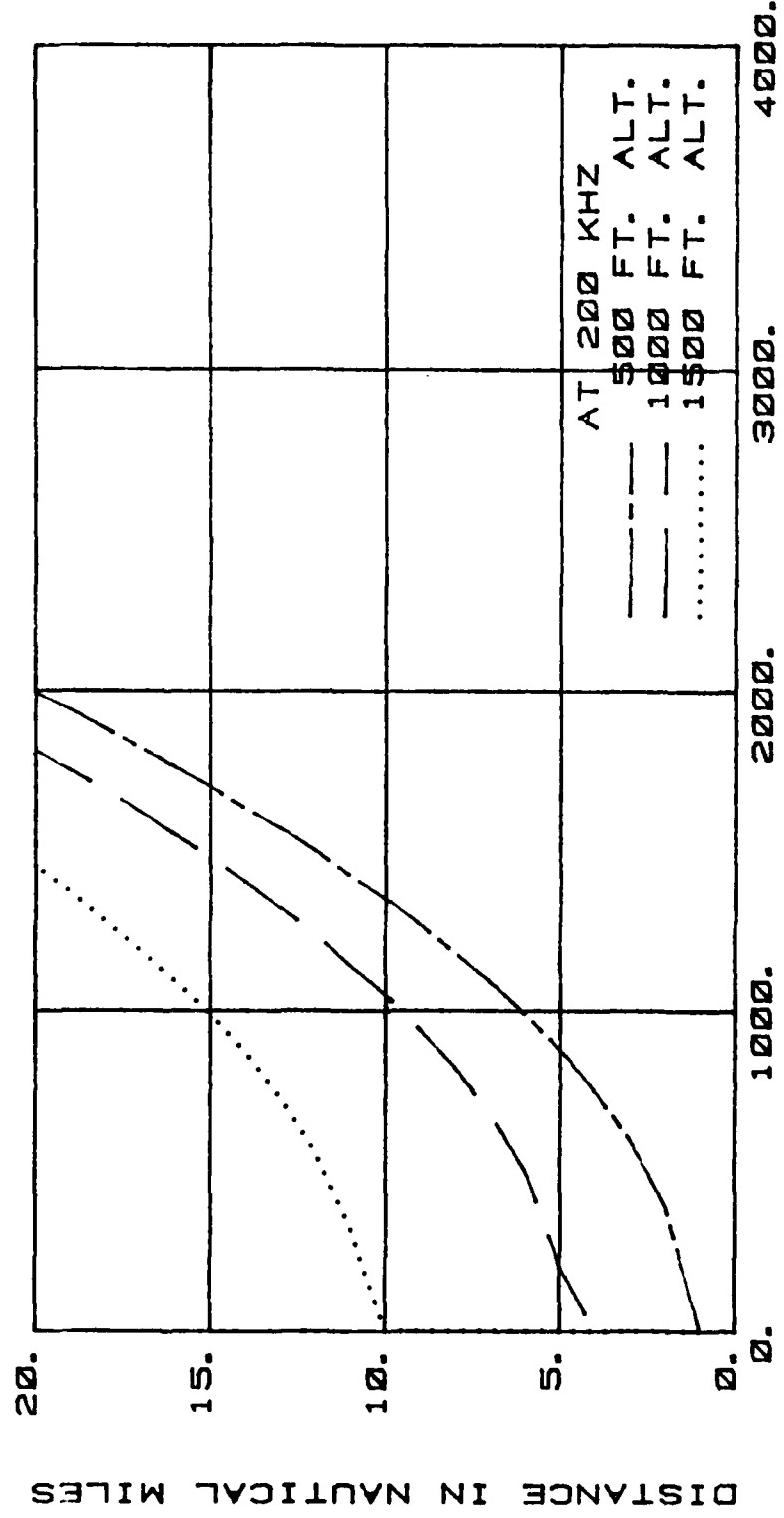
Critical Distance in Feet

Fig. 2.13a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 345 KV, f = 200 kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.13b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 345 kV, f = 500 kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.14a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 500 KV, f = 200 kHz, under heavy rain condition.

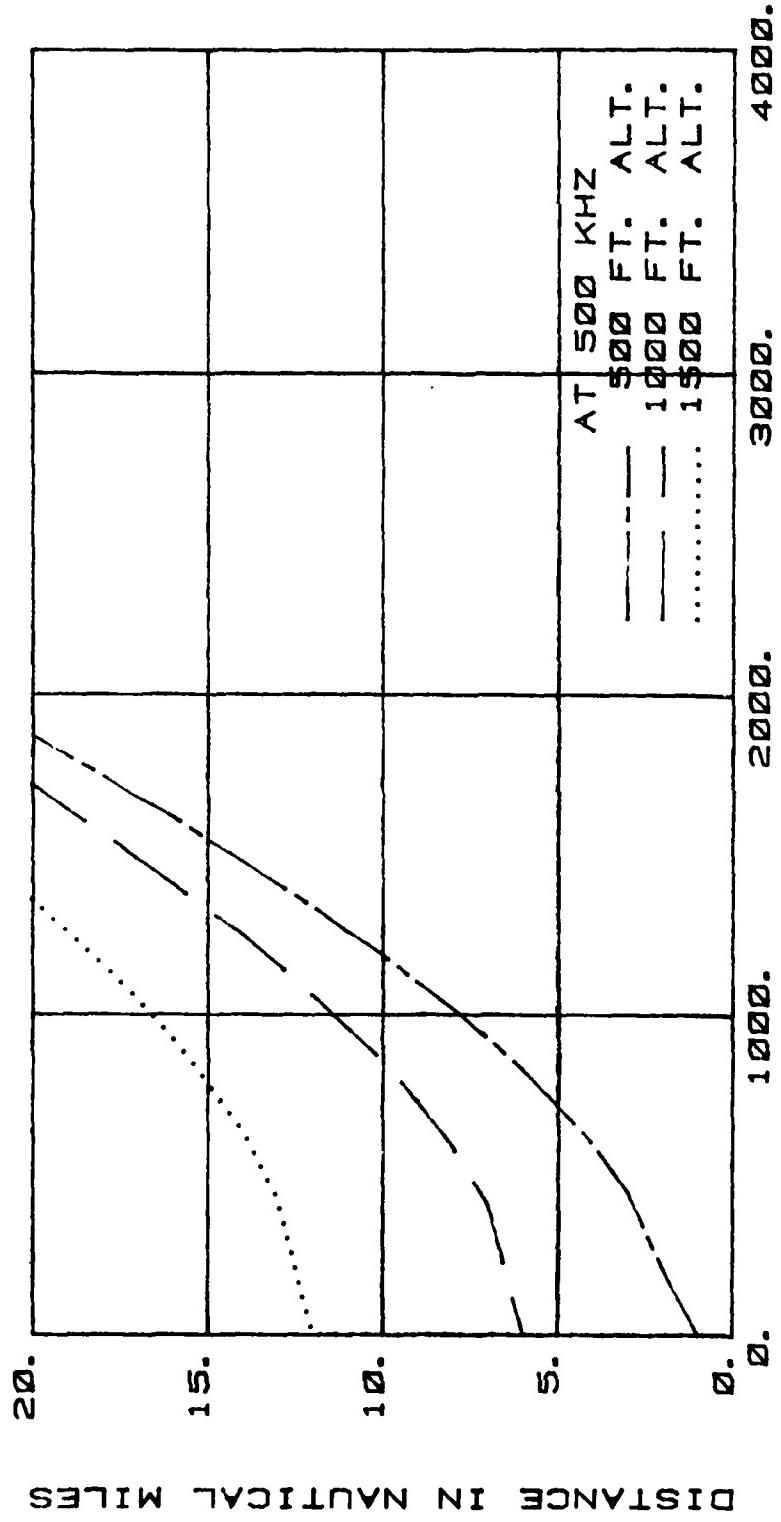
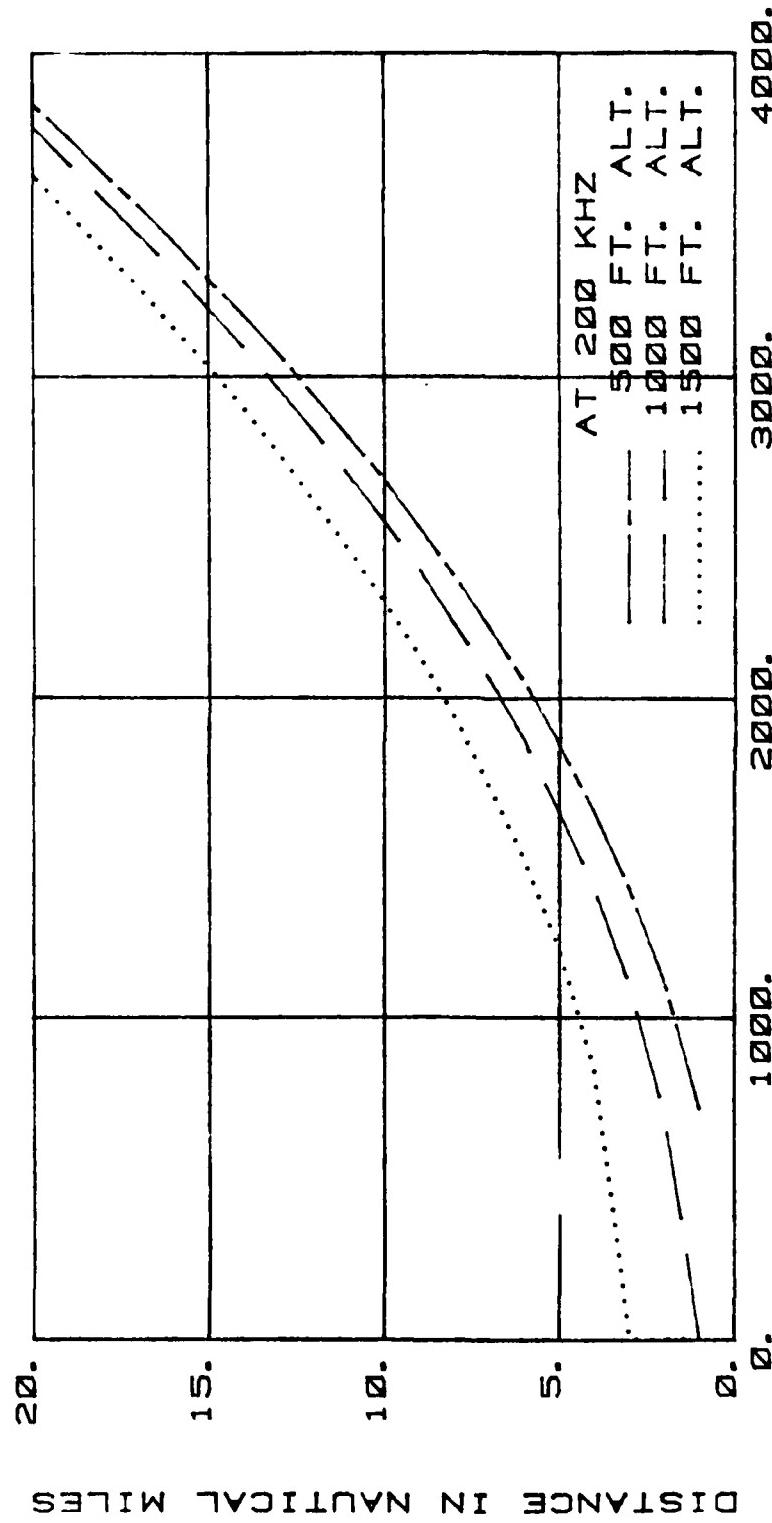
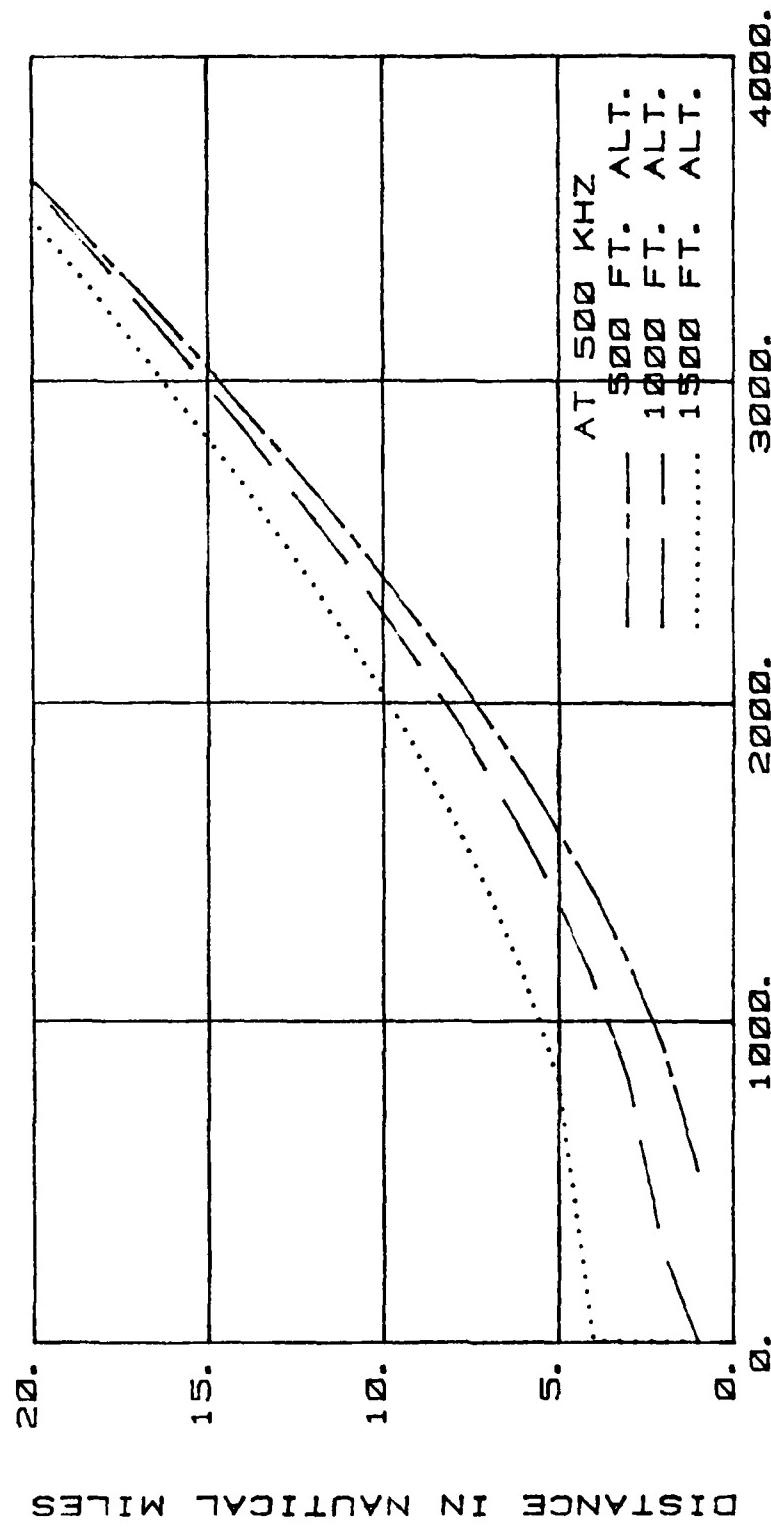


Fig. 2.14b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 500 kV, f = 500 kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.15a Critical distance from aircraft to powerline for 15 dB S/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 765 kV, f = 200 kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.15b Critical distance from aircraft to powerline for 15 dB S/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 765 KV, f = 500 kHz, under heavy rain condition.

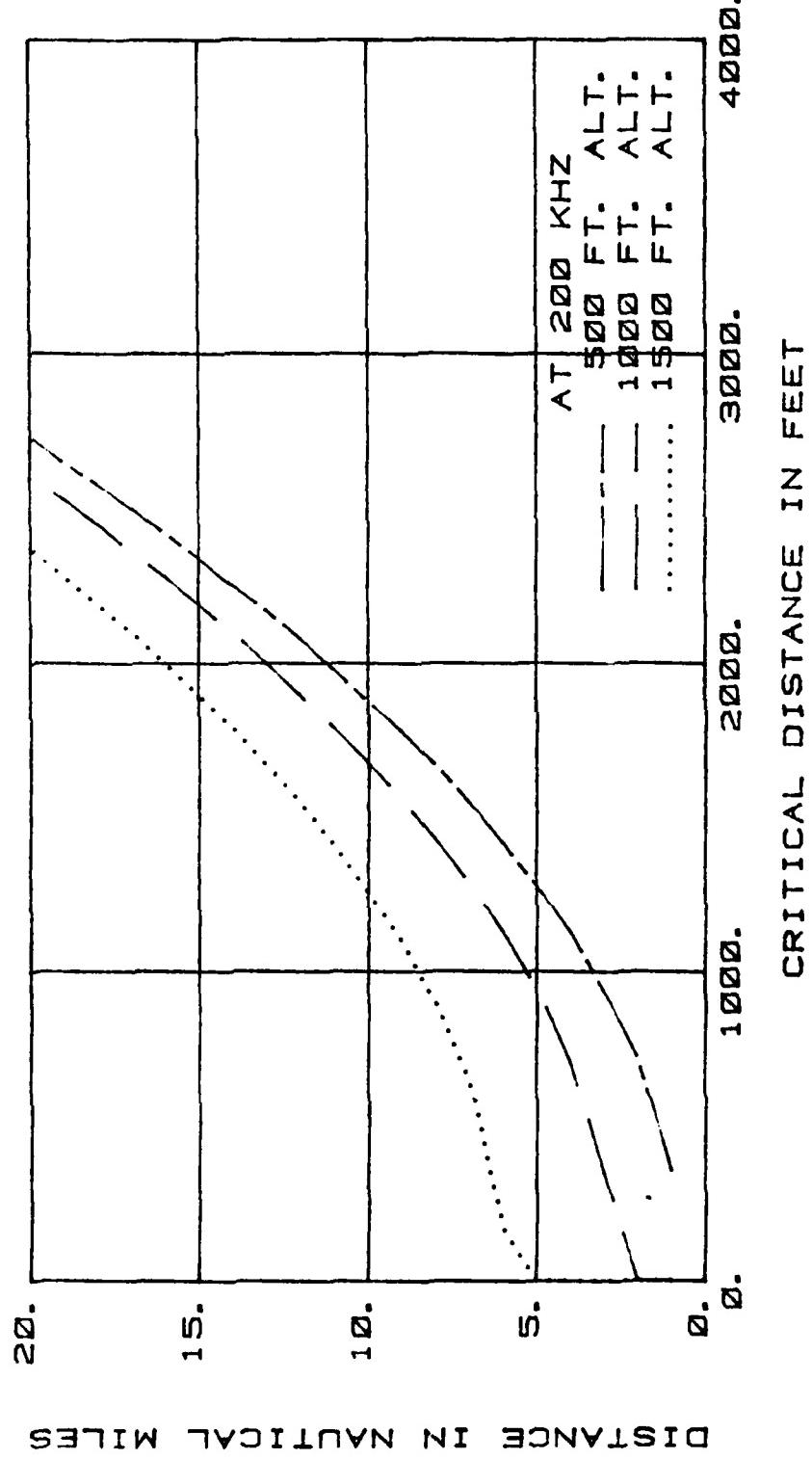
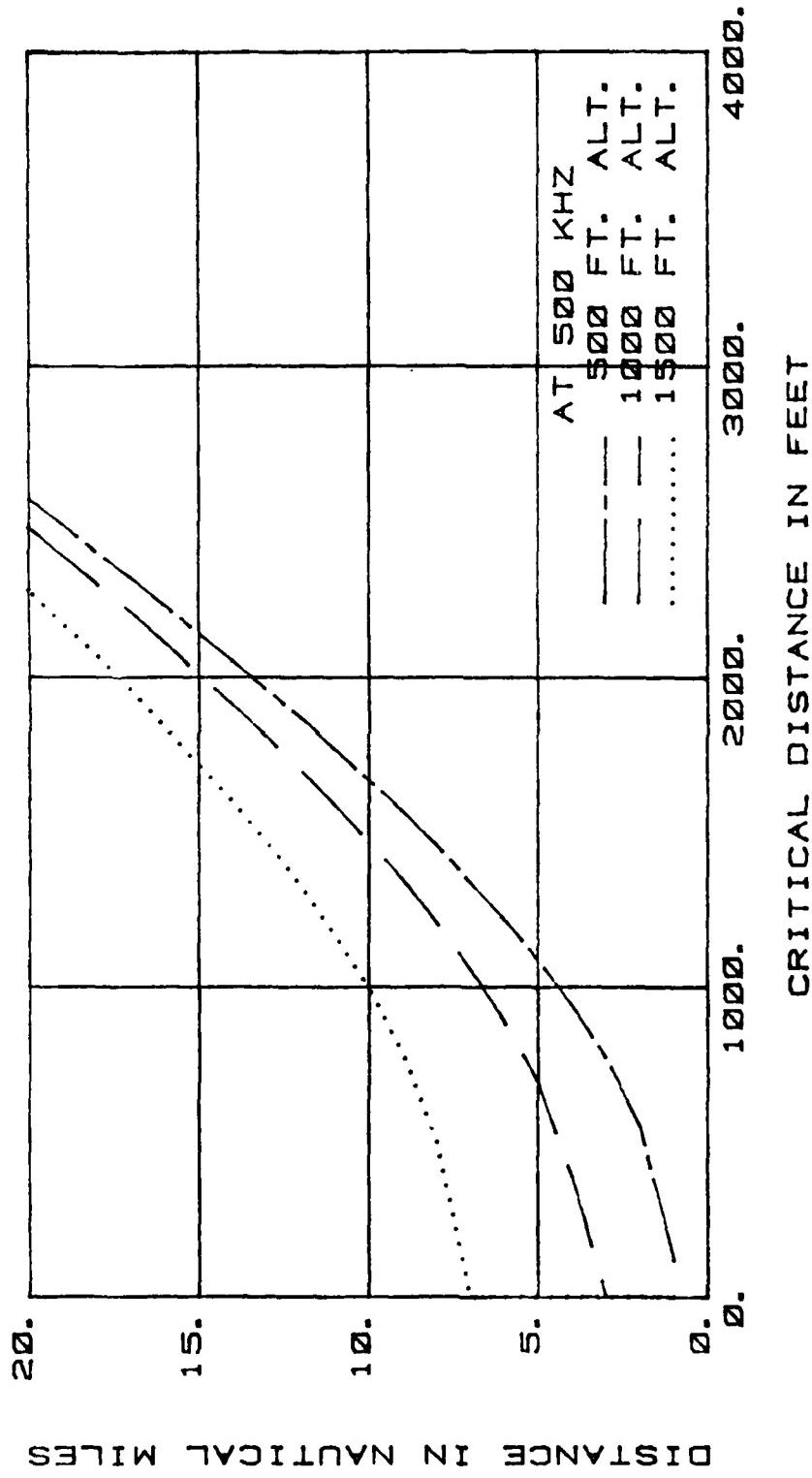


Fig. 2.16a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitude and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 1100 kV, f = 200 Hz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.16b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 1100 KV, f = 500 kHz, under heavy rain condition.

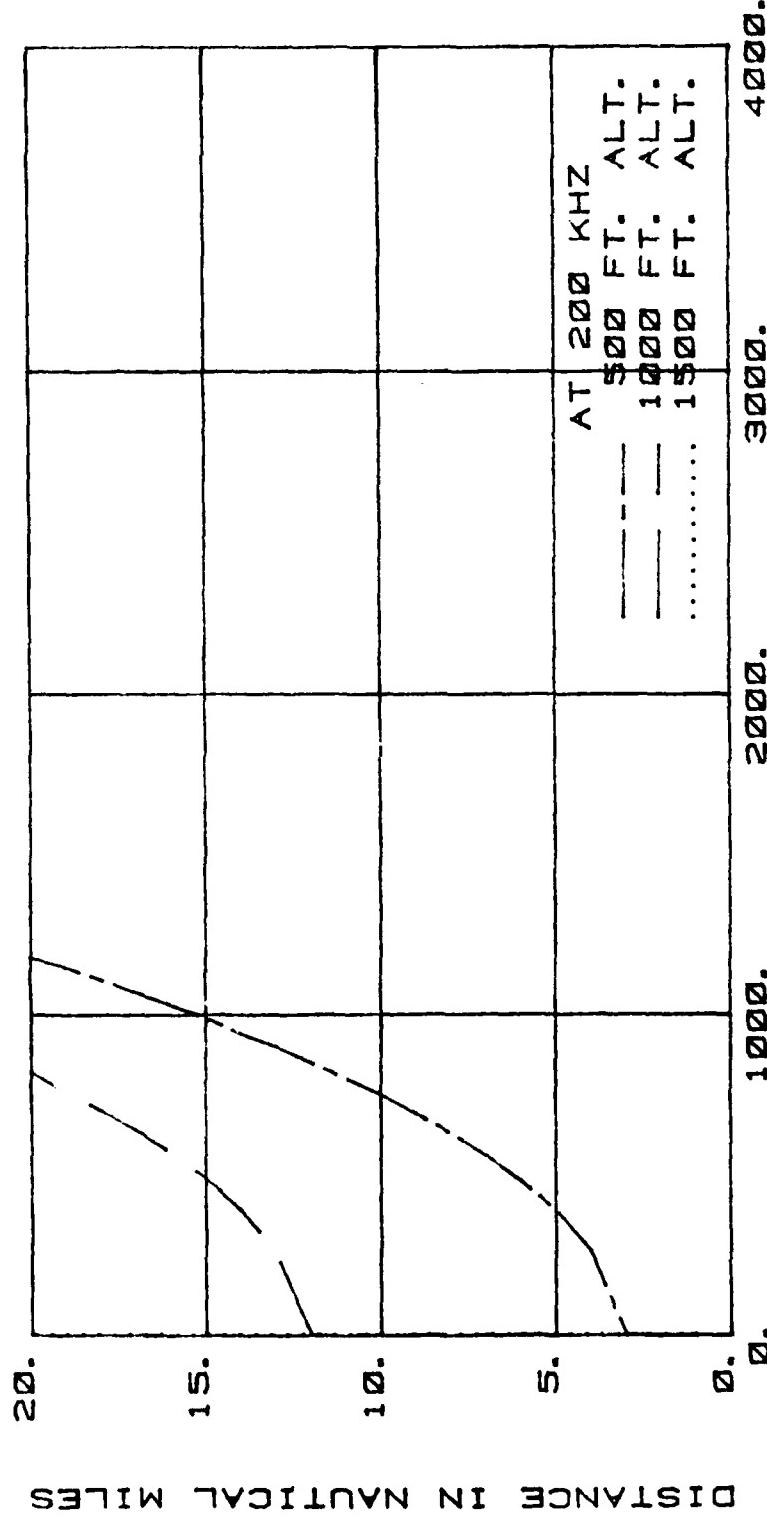


Fig. 2.17a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 345 KV, f = 200 kHz, under heavy rain condition.

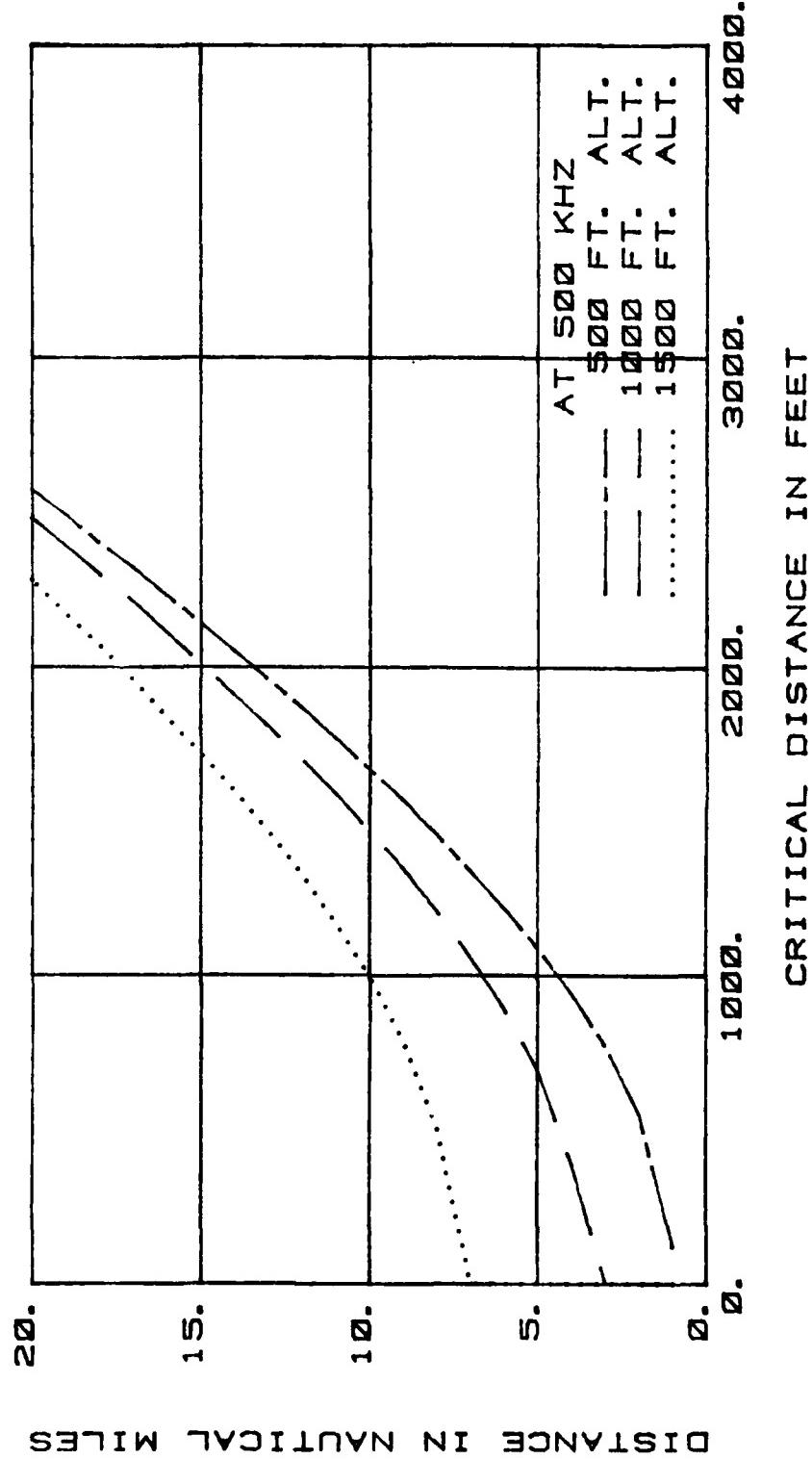
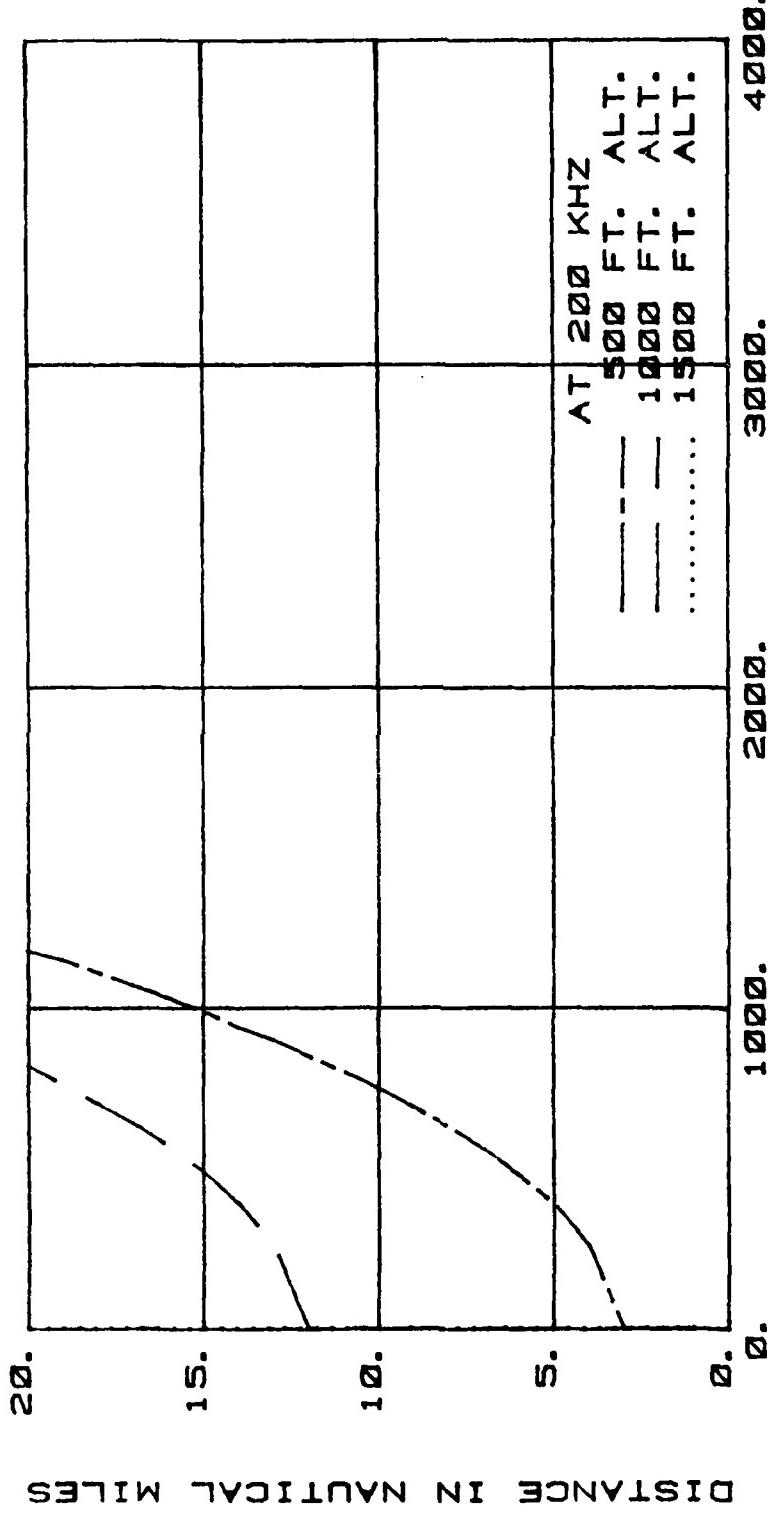
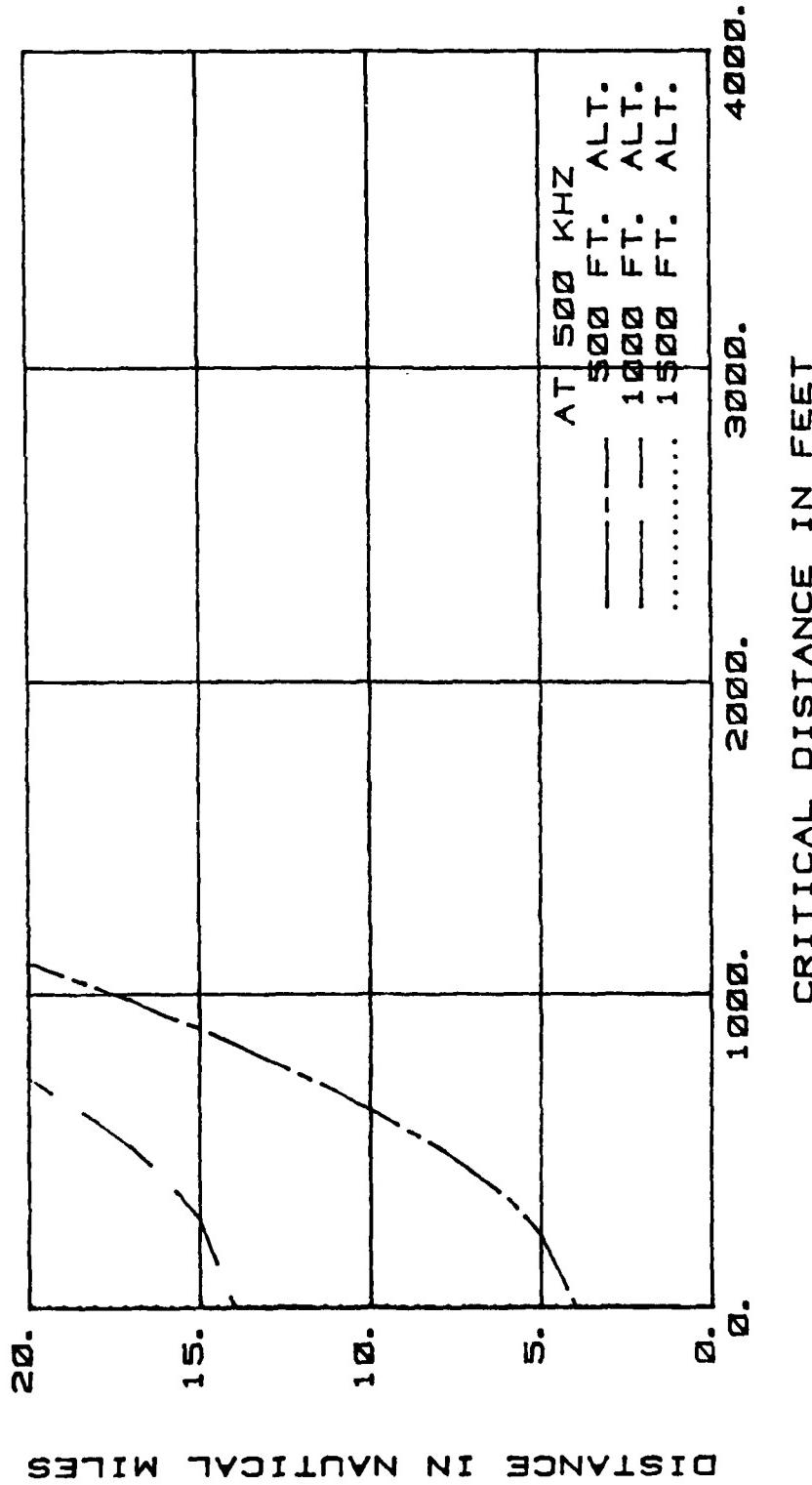


Fig. 2.16b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = 1100 KV, f = 500 kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.17a Critical distance from aircraft to powerline for 15 dB S/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 345 KV, f = 200 kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.17b Critical distance from aircraft to powerline for 15 dB S/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 345 KV, f = 500 kHz, under heavy rain condition.

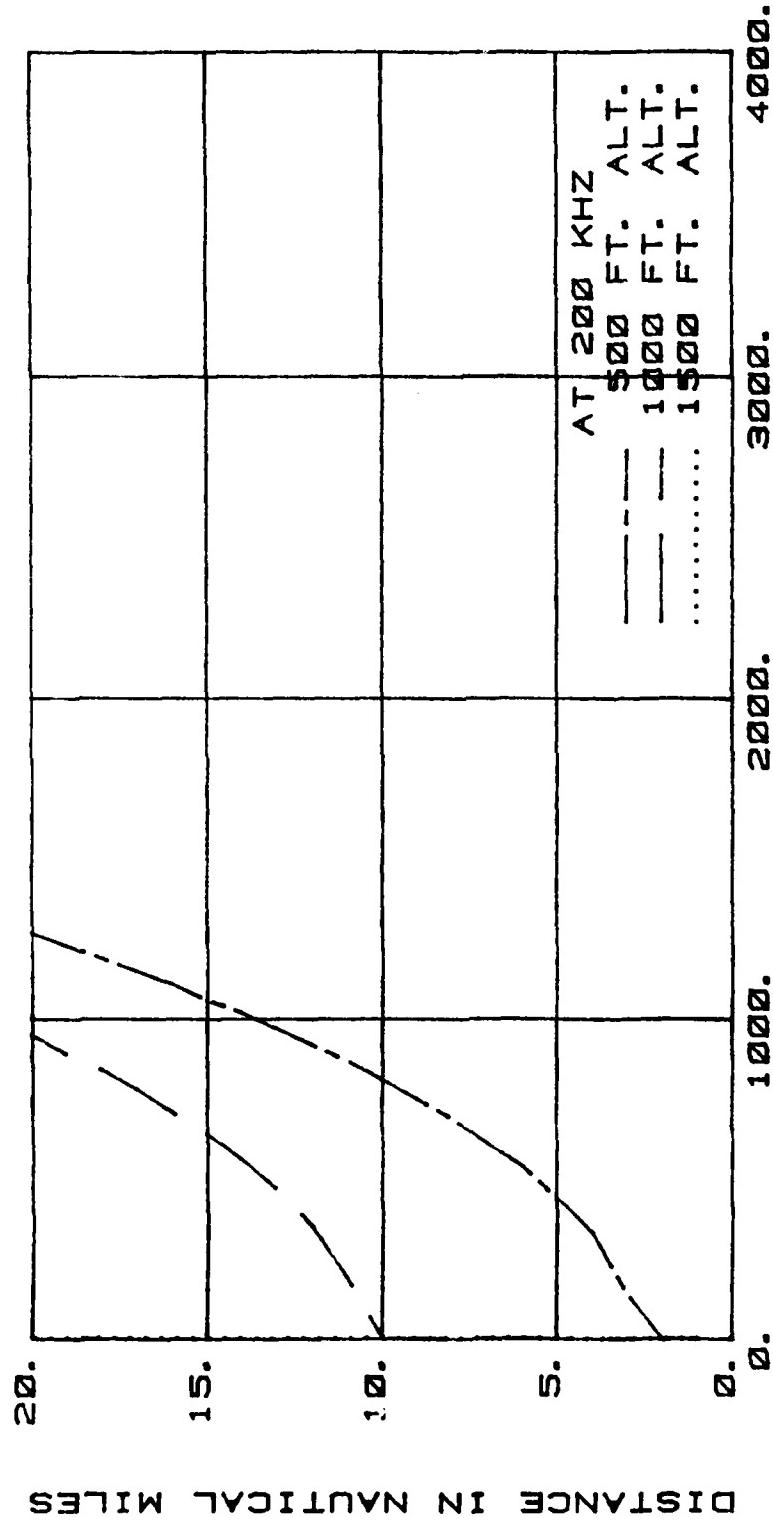


Fig. 2.18a Critical distance from aircraft to powerline for 15 dB S/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 500 kV, f = 200 kHz, under heavy rain condition.

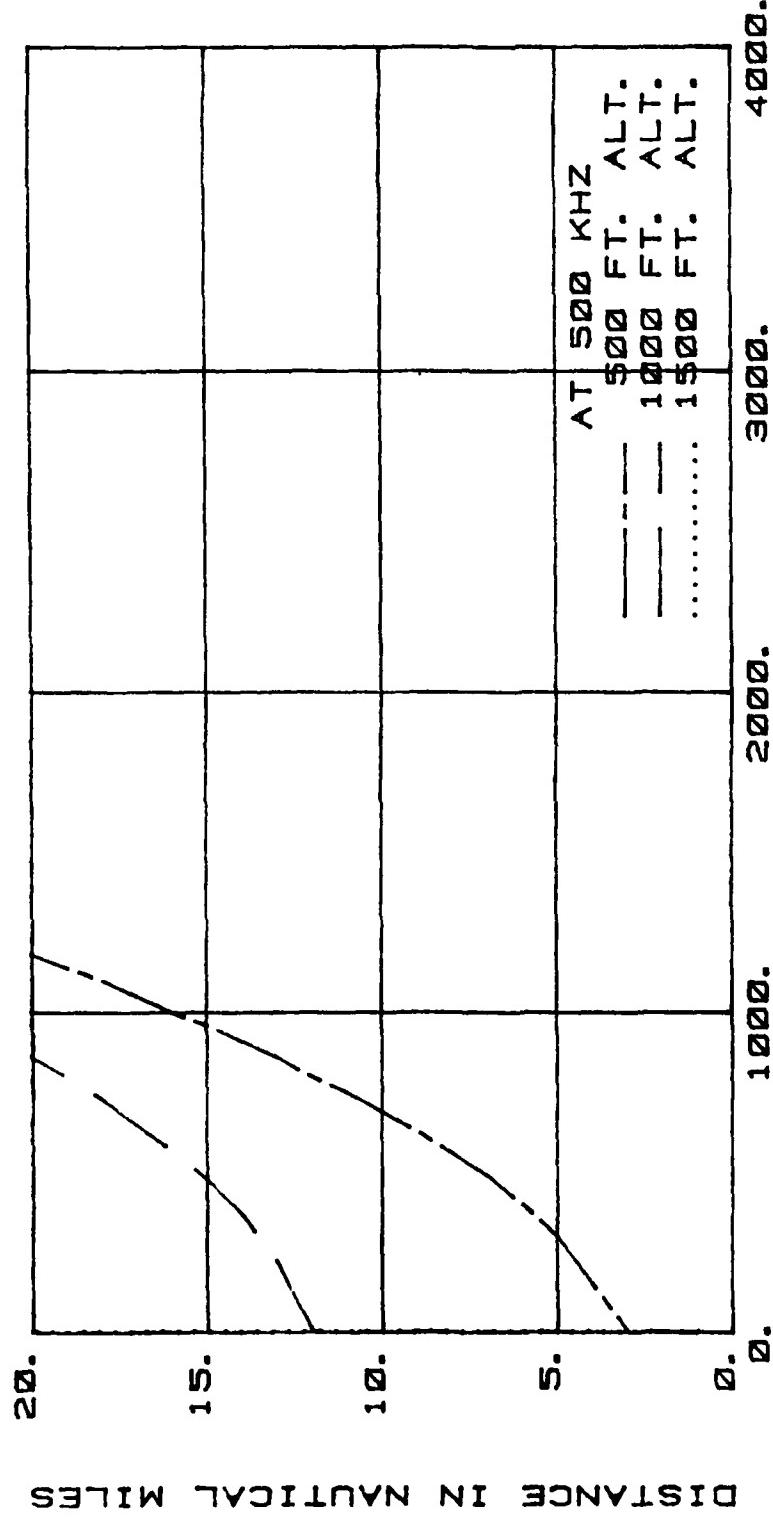
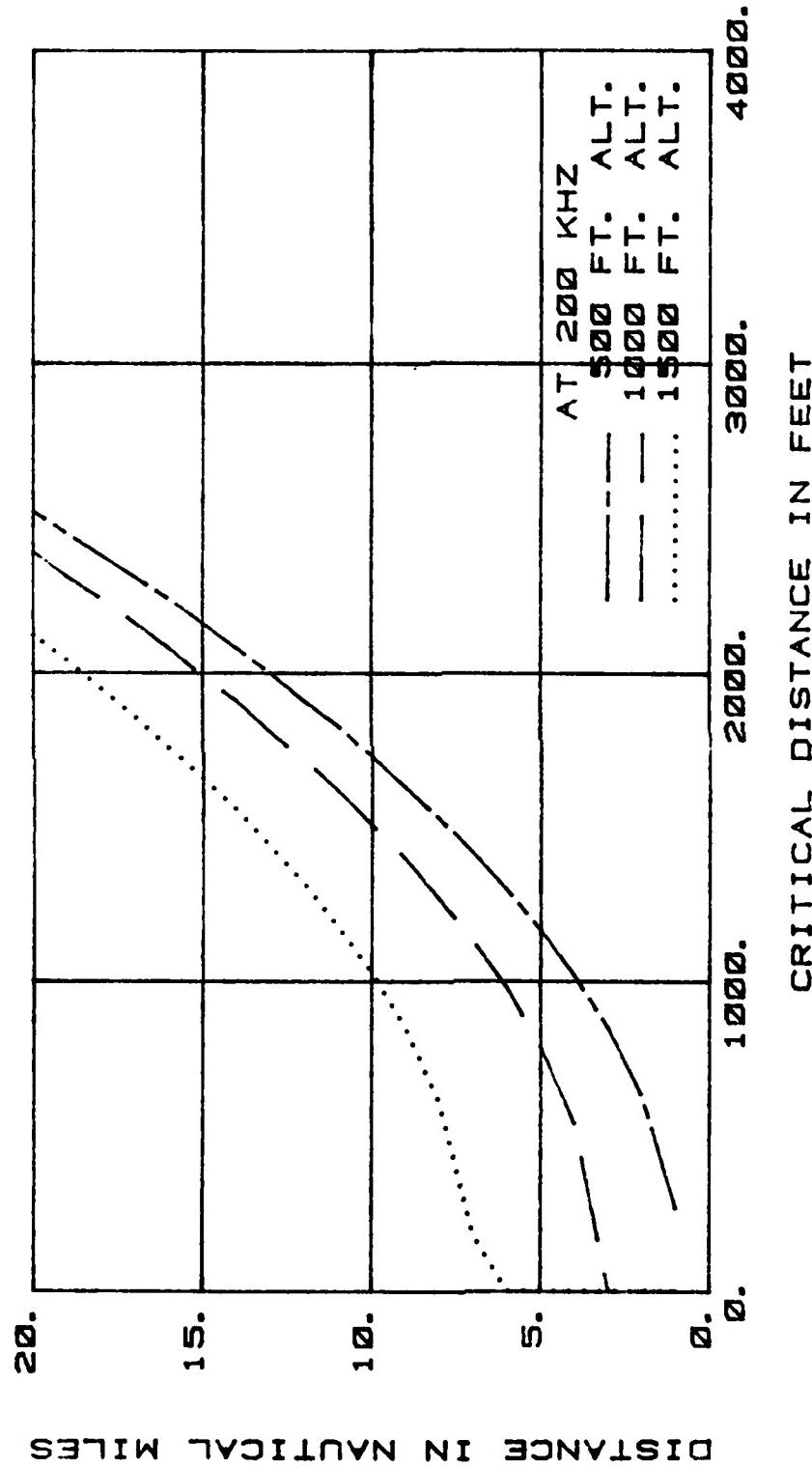
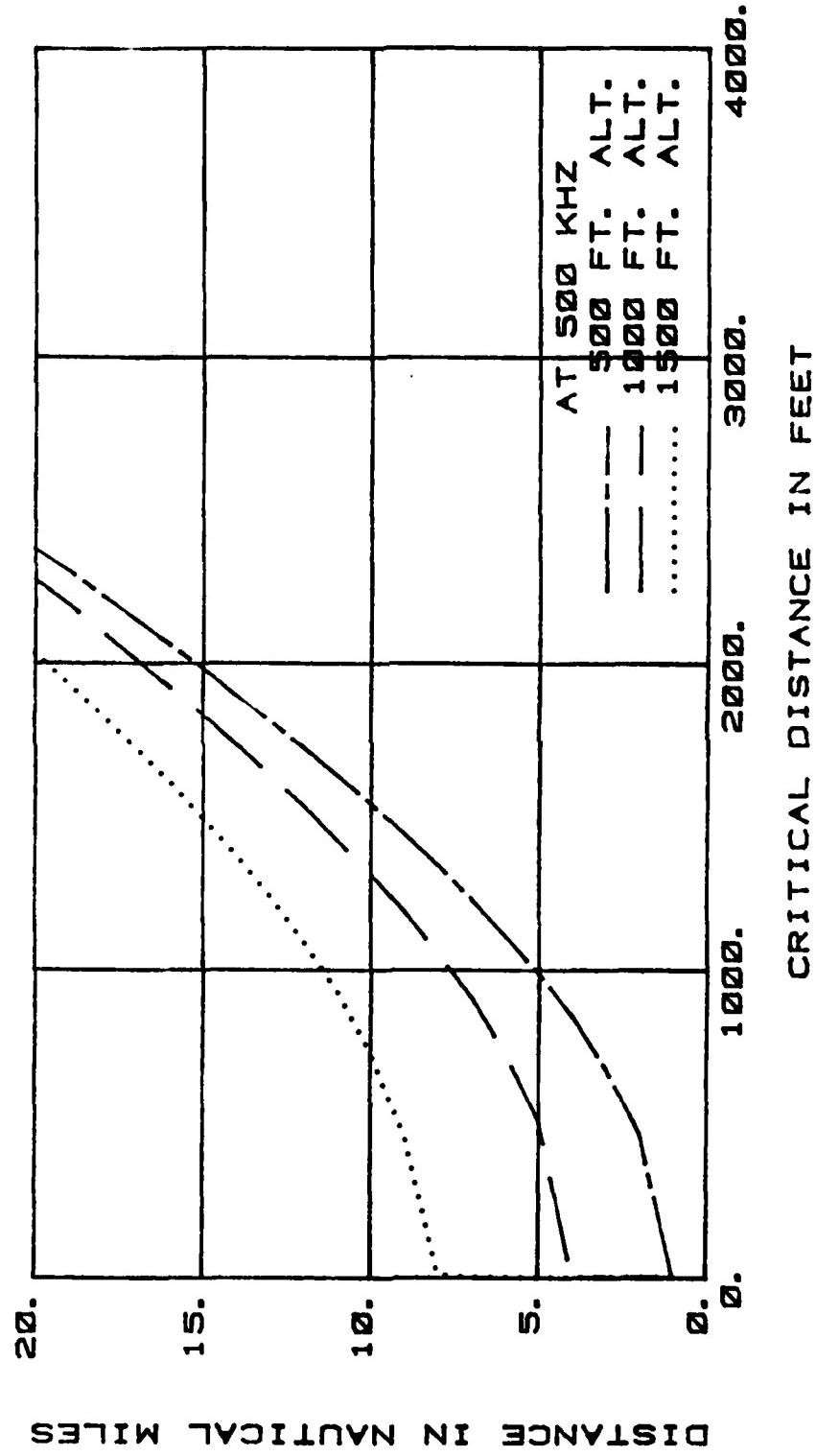


Fig. 2.18b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 500 KV, f = 500 kHz, under heavy rain condition.



Critical Distance in Feet

Fig. 2.19a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 765 KV, f = 200 kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.19b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 765 kV, f = 500 kHz, under heavy rain condition.

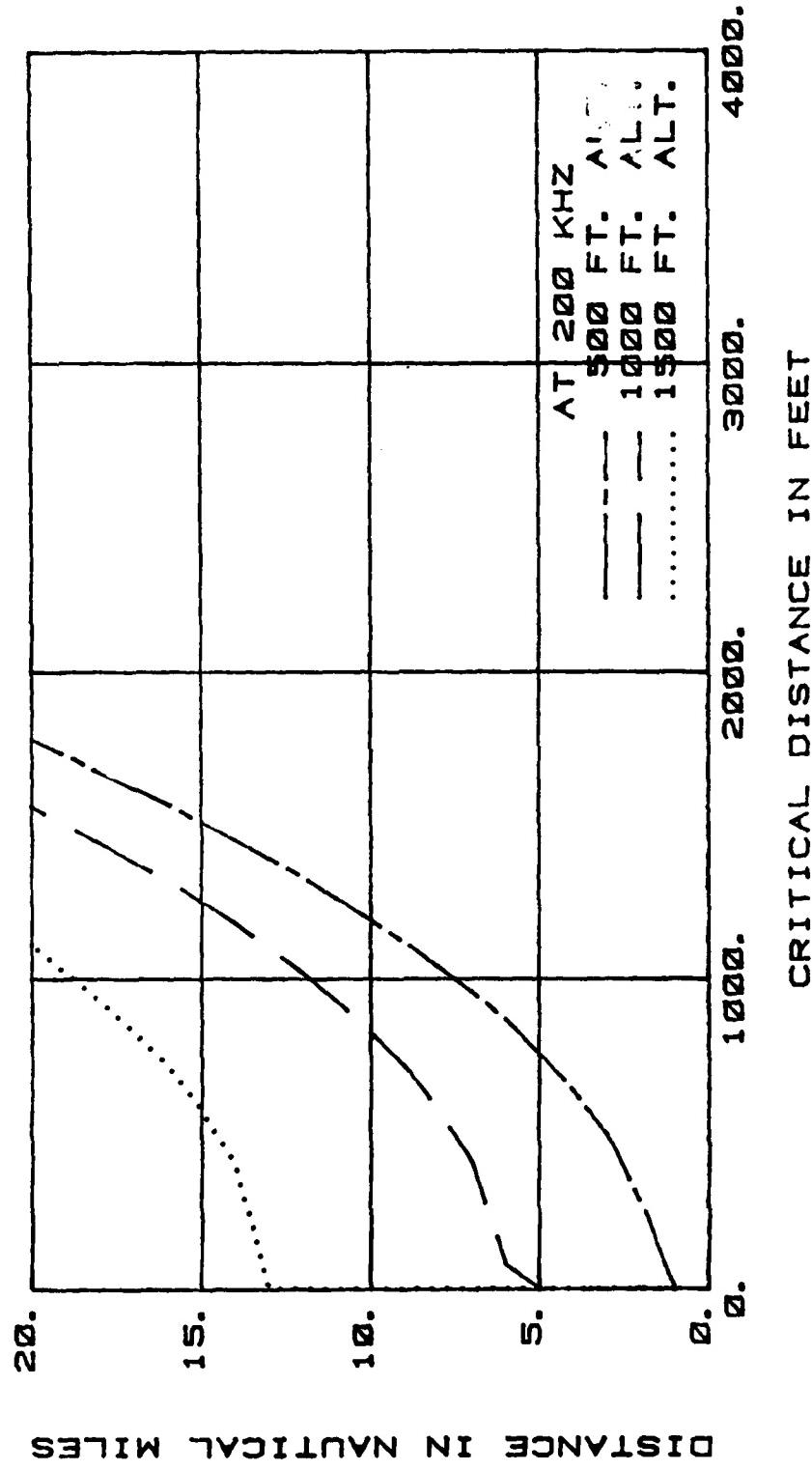
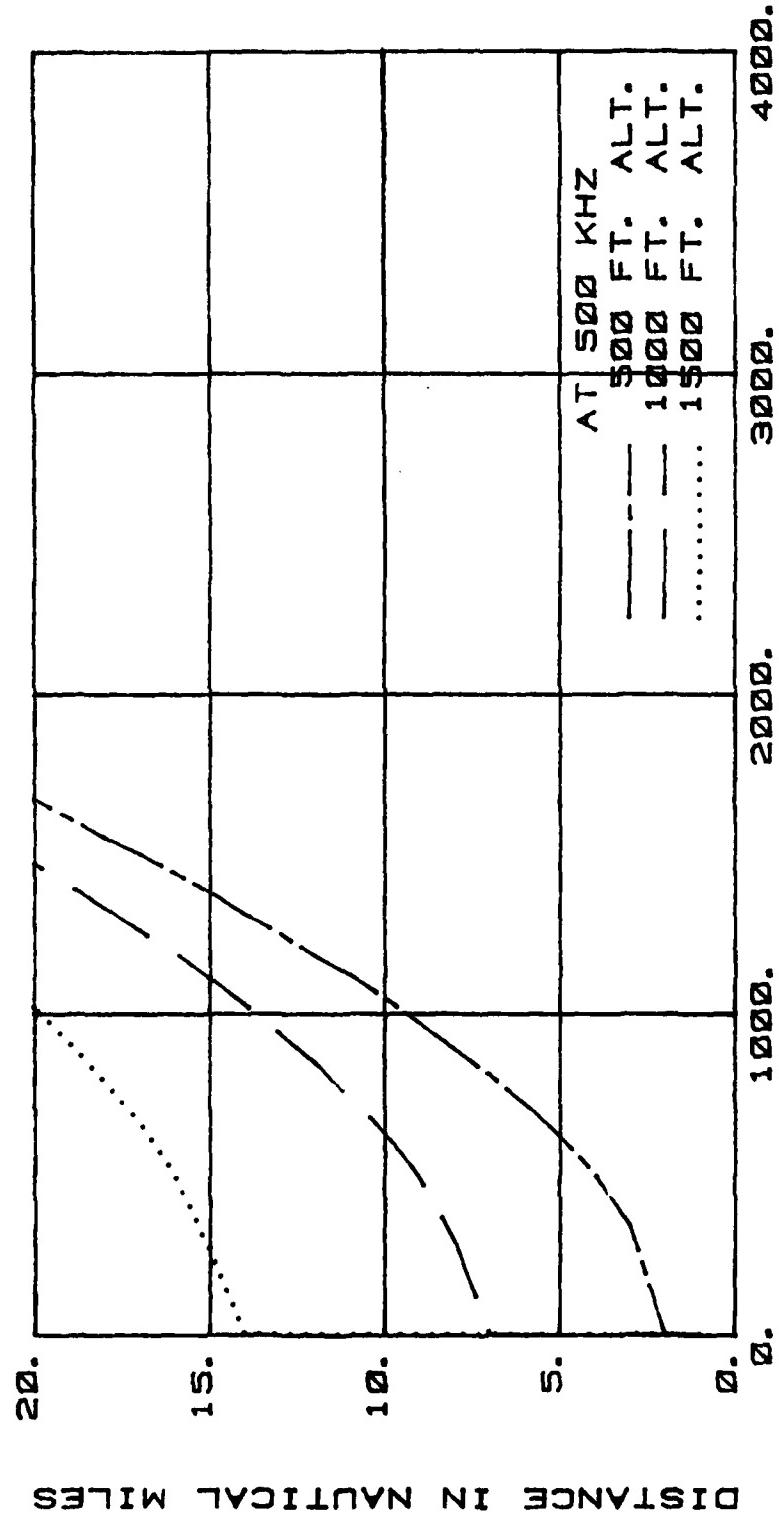
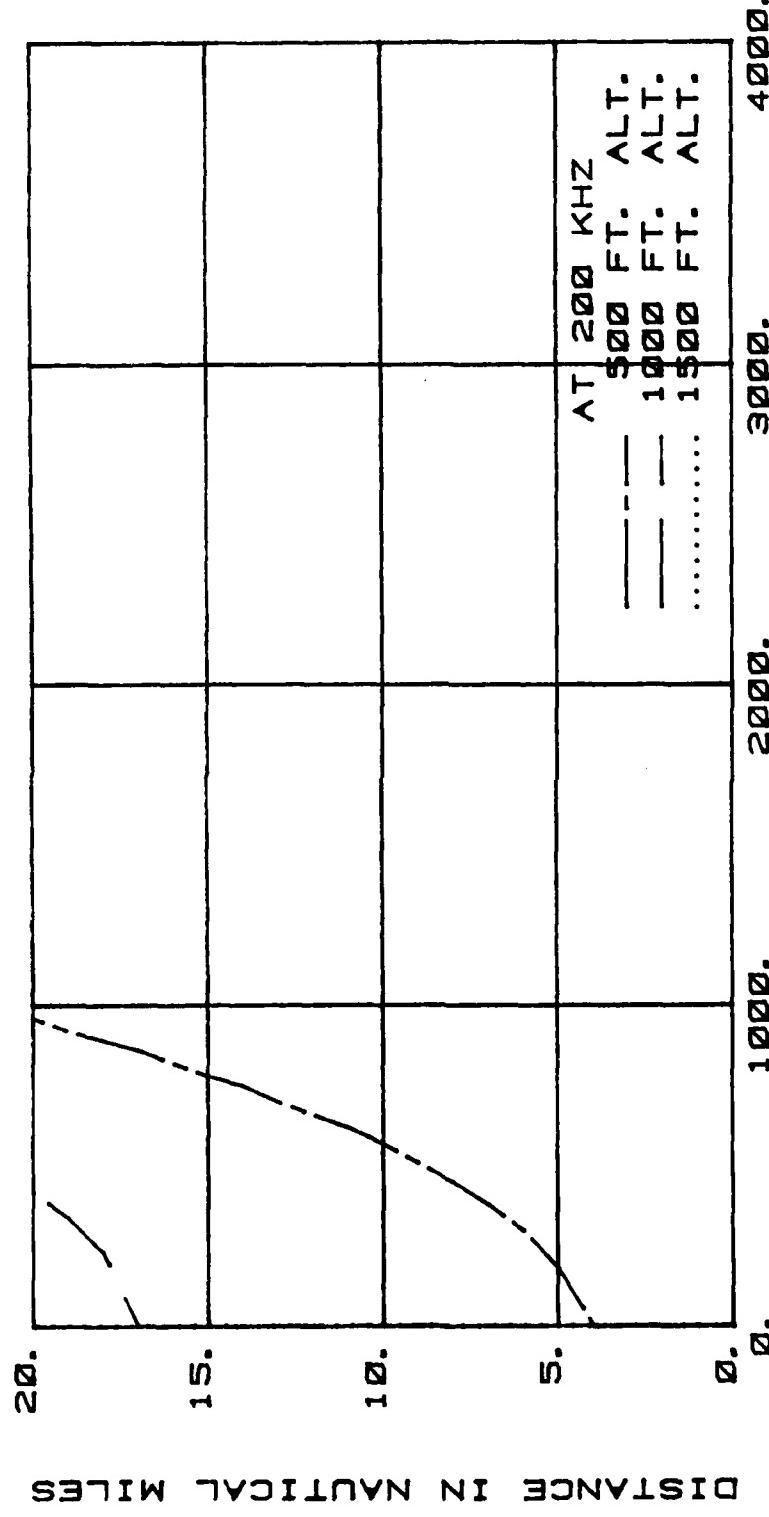


Fig. 2.20a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 1100 kV, f = 200 kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.20b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.5 watt, line voltage = 1100 KV, f = 500 kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.21a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 345 KV, f = 200 kHz, under heavy rain condition.

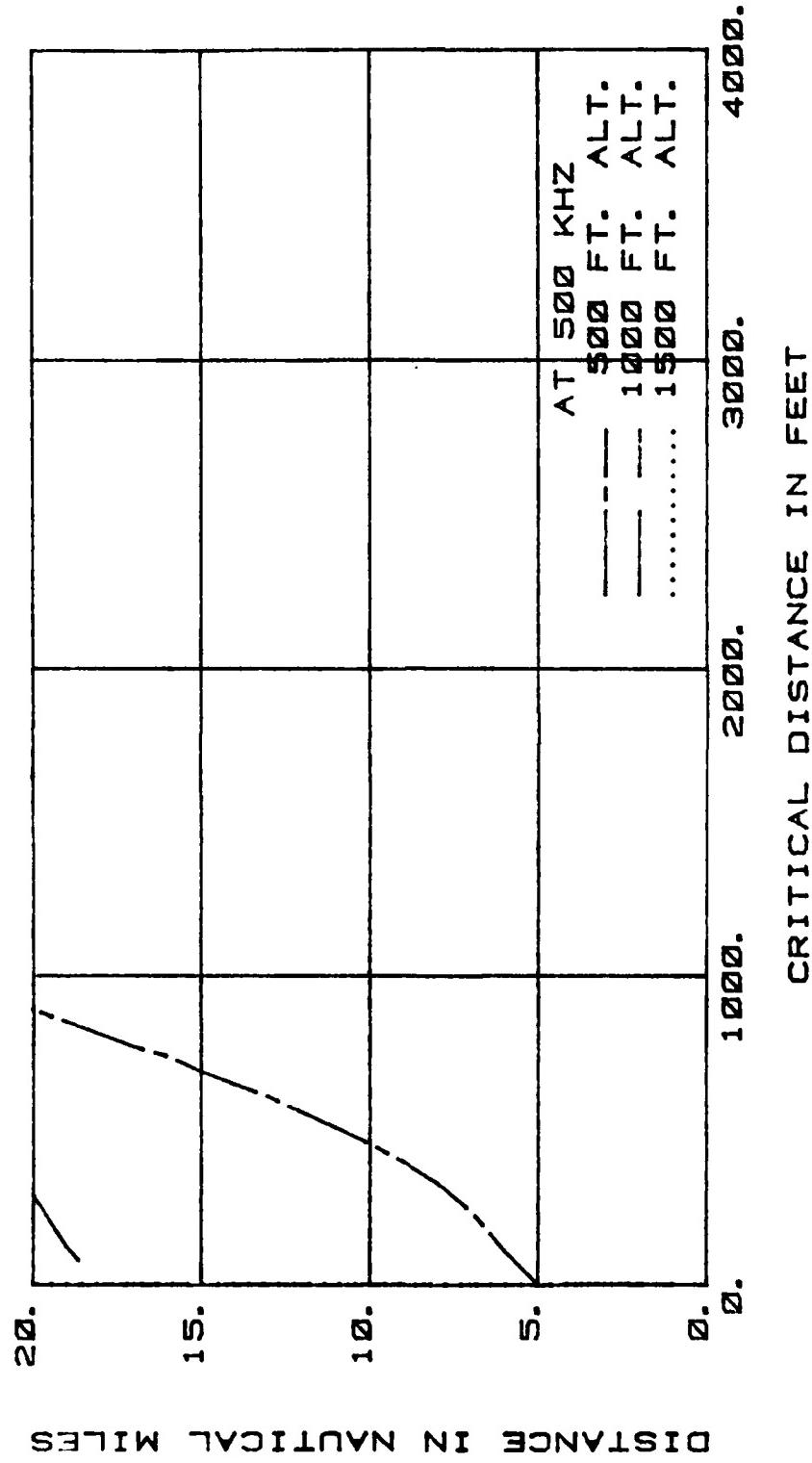


Fig. 2.21b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 345 kV, f = 500 kHz, under heavy rain condition.

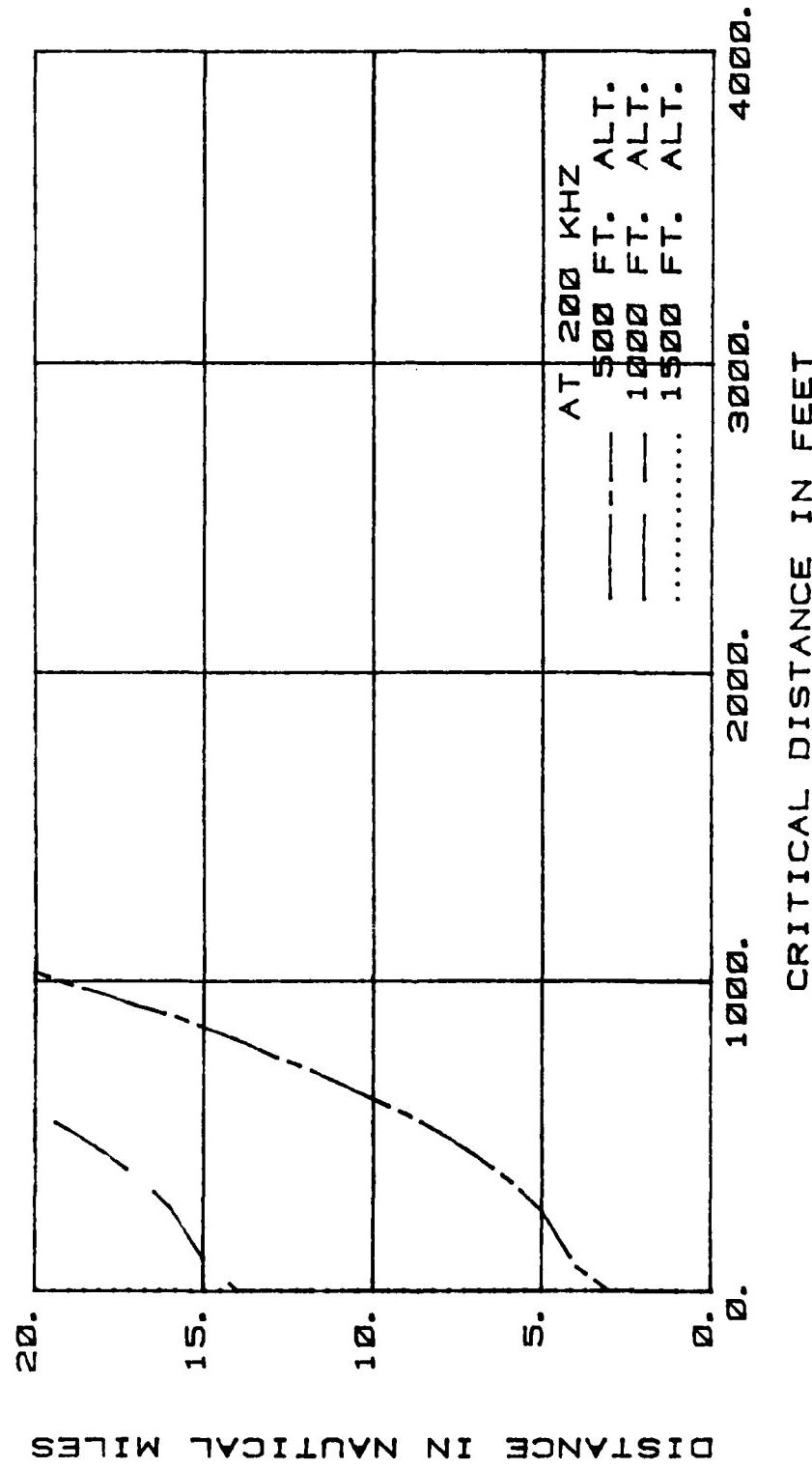
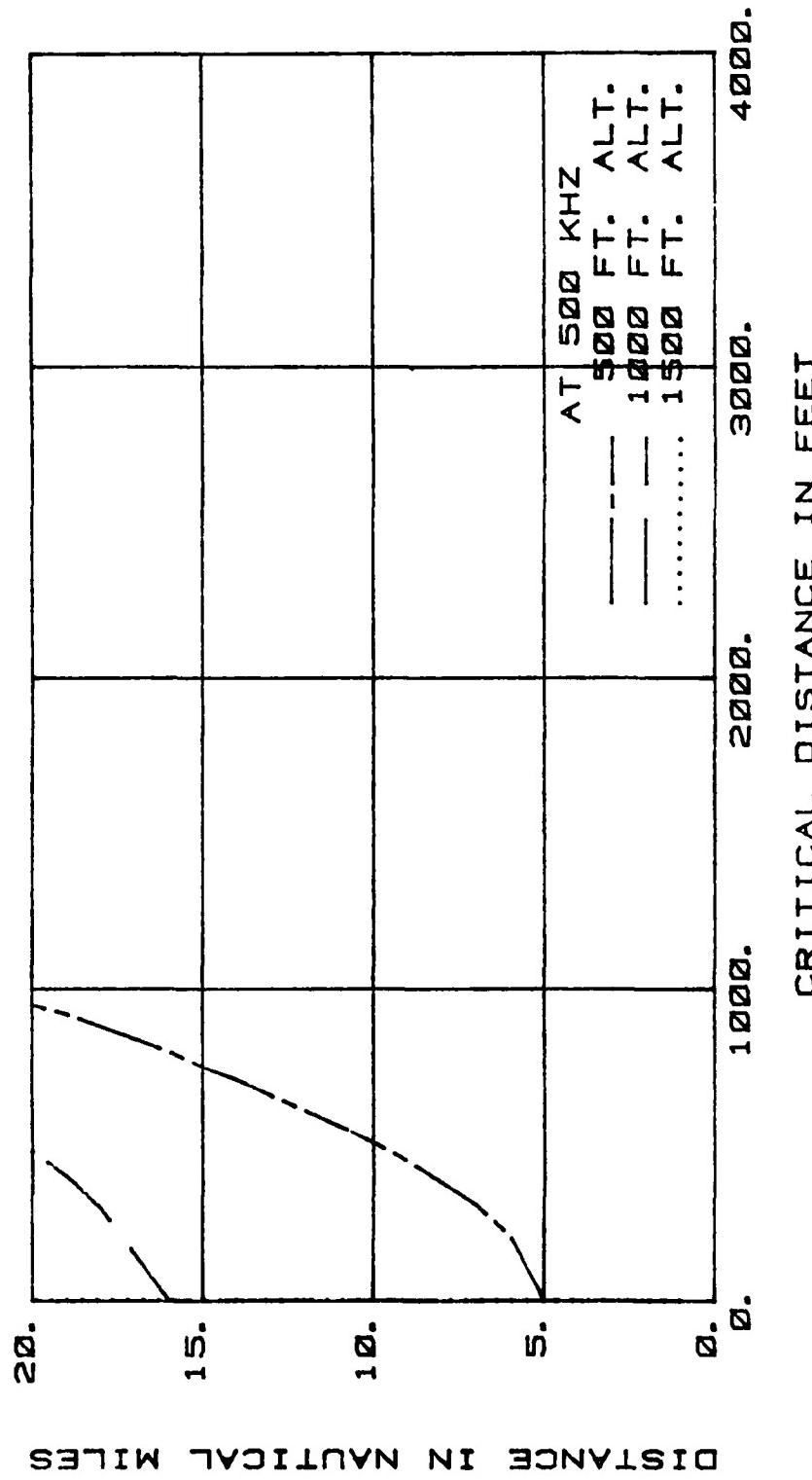
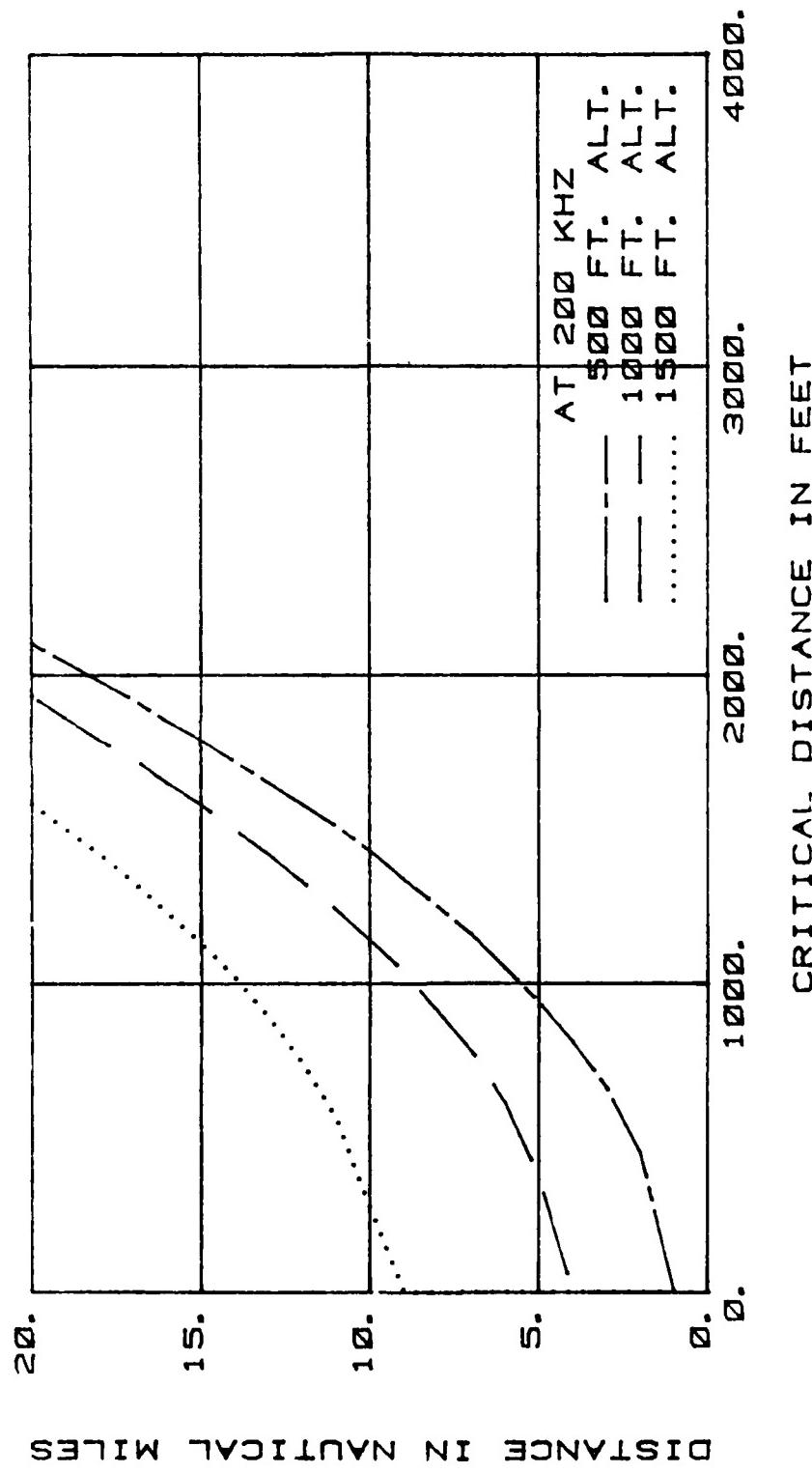


Fig. 2.22a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 500 KV, f = 200 kHz, under heavy rain condition.



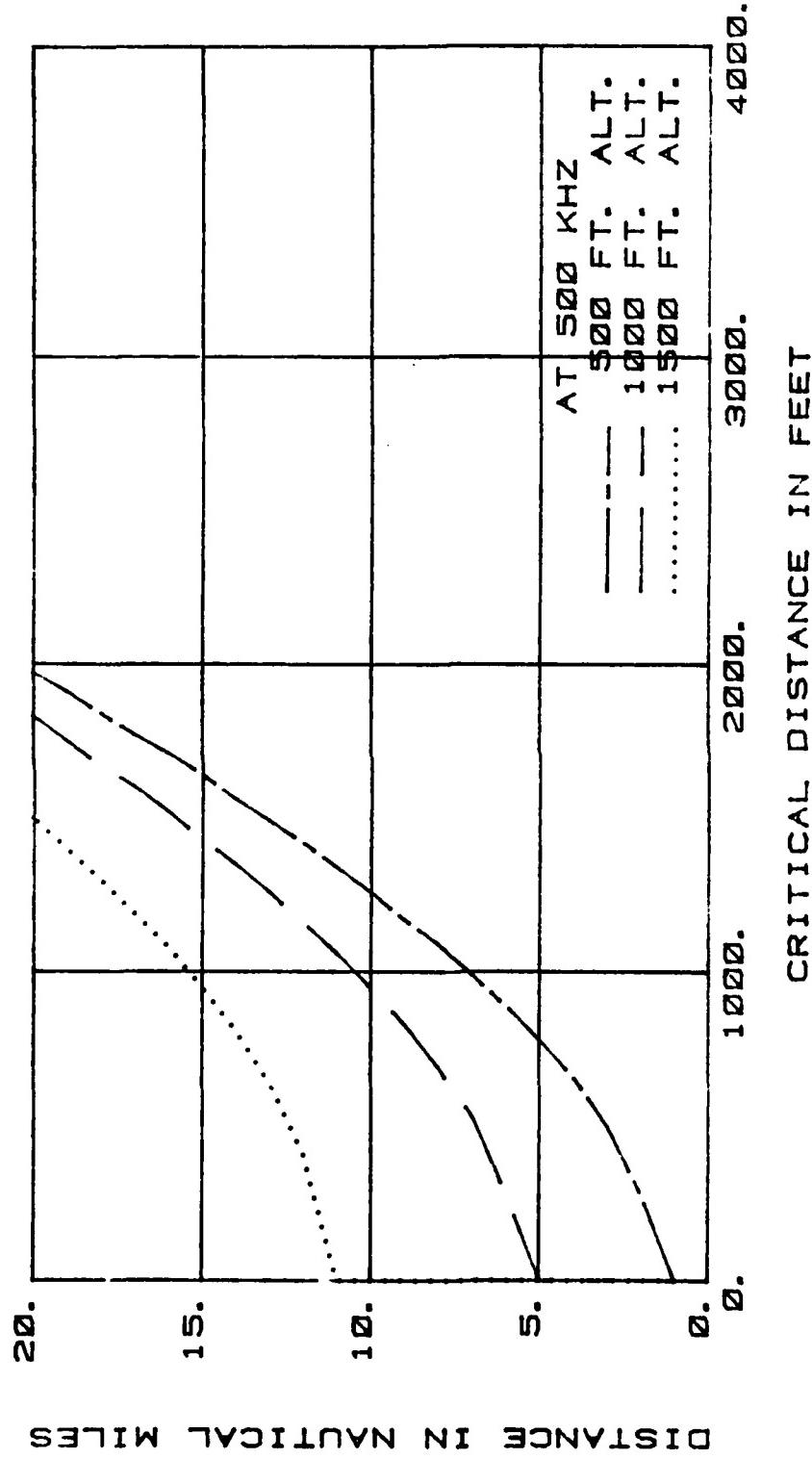
CRITICAL DISTANCE IN FEET

Fig. 2.22b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 500 KV, f = 500 kHz, under heavy rain condition.



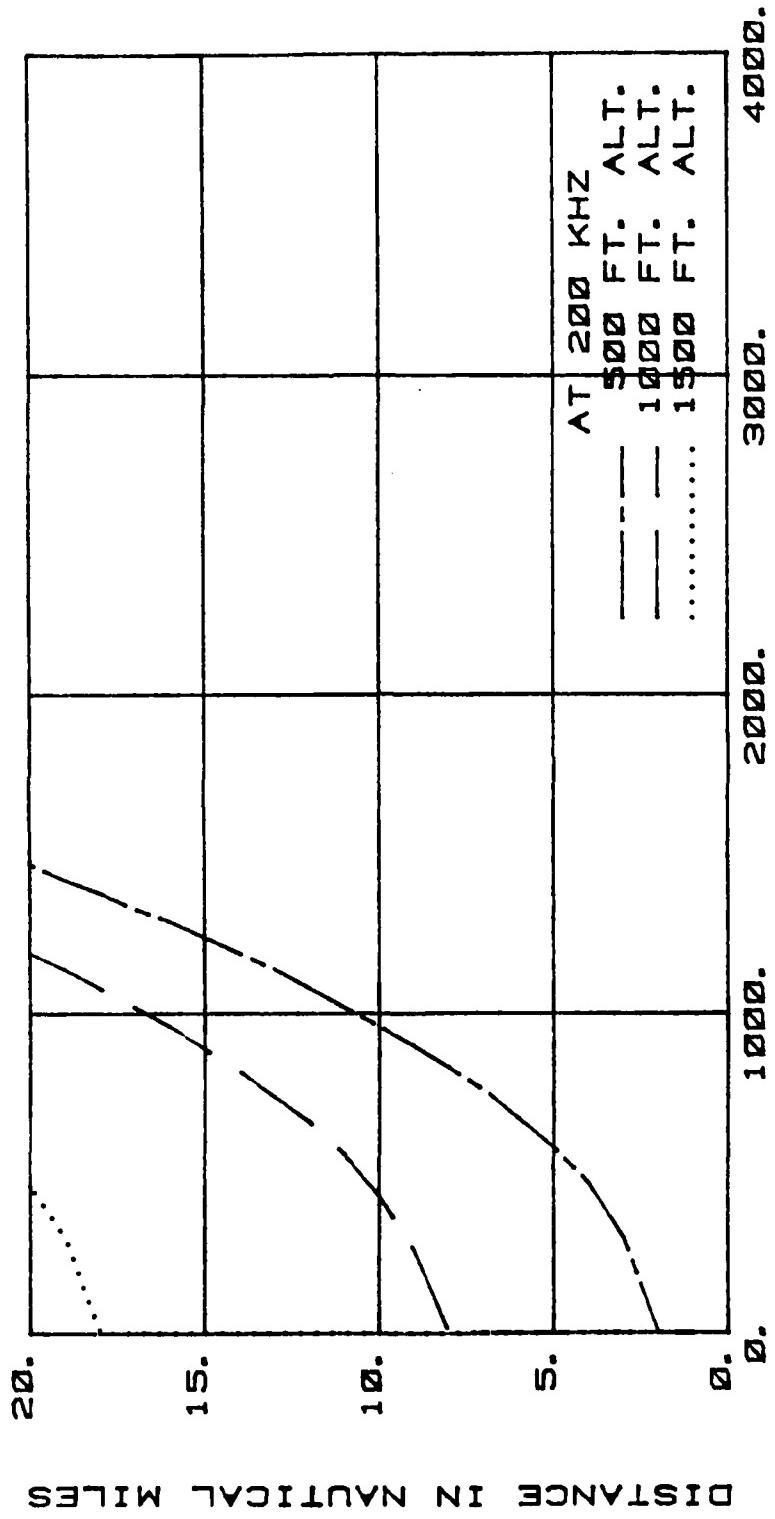
CRITICAL DISTANCE IN FEET

Fig. 2.23a Critical distance from aircraft to powerline for 15 dB S/n ratio as a function of aircraft altitudes and distance from NPB transmitter to powerline; I_{RP} = 1.0 watt, line voltage = 765 KV, f = 300 Hz, in a heavy rain condition.



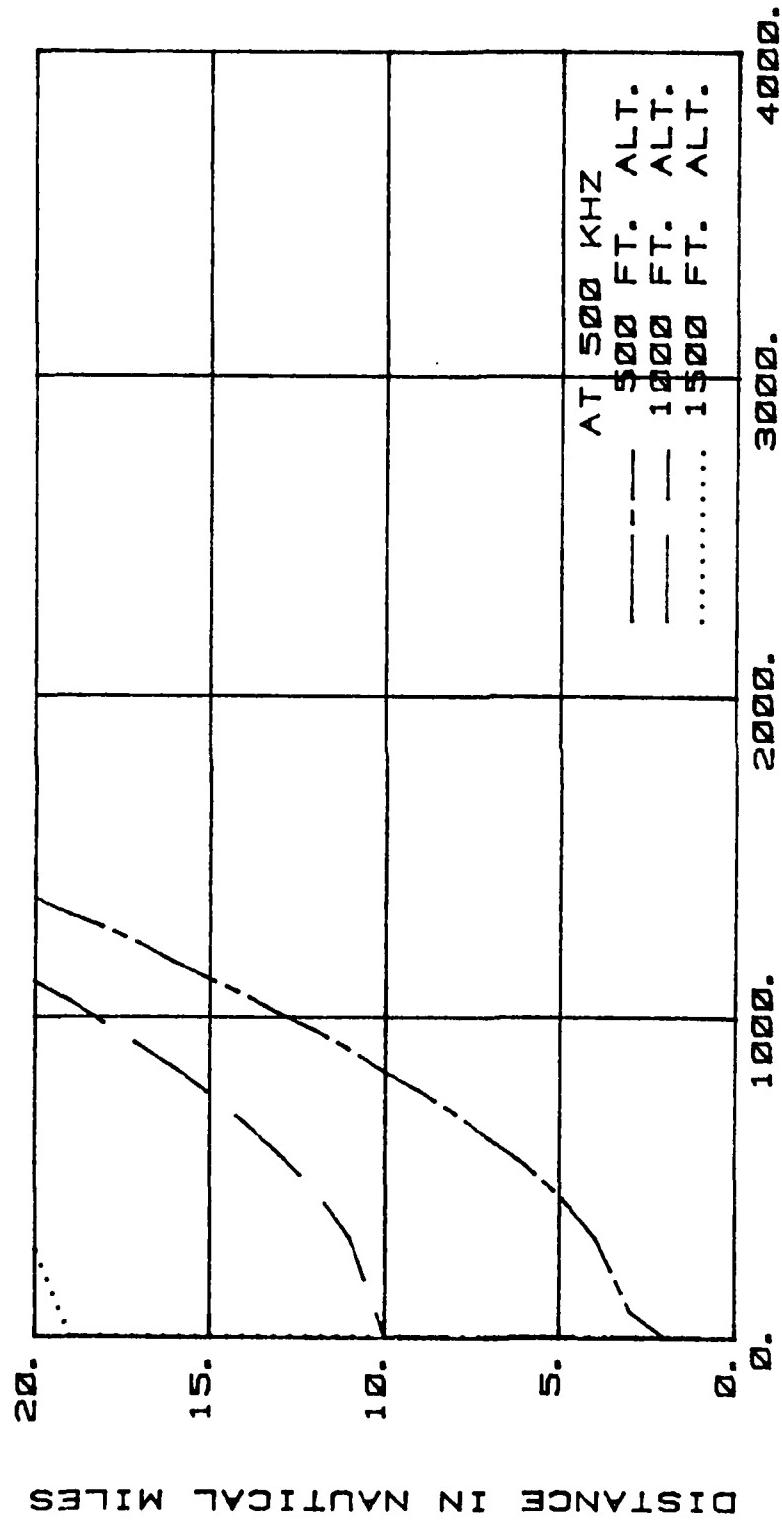
CRITICAL DISTANCE IN FEET

Fig. 2.23b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 765 kV, $f = 500$ kHz, under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.24a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 1100 kV, $f = 200$ kHz under heavy rain condition.



CRITICAL DISTANCE IN FEET

Fig. 2.24b Critical distance from aircraft to powerline for 15 dB S/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 1.0 watt, line voltage = 1100 KV, f = 500 kHz, under heavy rain condition.

Chapter III

PREDICTION OF RADIO INTERFERENCE NOISE FROM DC POWERLINES

3.1 Introduction

Direct-current powerlines can be classified into three types.

They are: 1) the monopolar link, 2) the bipolar link and 3) the homopolar link.

- 1) The monopolar link has one conductor, usually of negative polarity, and ground or sea return.
- 2) The bipolar link has two conductors, one positive and the other negative.
- 3) The homopolar link has two or more conductors all having the same polarity, usually negative, and always operates with a ground return.

RI noise from DC powerlines, like its counterpart in AC powerlines, is also caused by corona discharges on the line conductors. Studies and reports^{12,13,14} have consistently shown that the major source of RI noise is from the positive conductor and that contribution from the negative conductor to the total RI noise is practically negligible. Based on the conclusion, the prediction method outlined here for the RI noise from the DC powerlines will only consider the bipolar link.

As opposed to RI noise from AC powerlines, RI noise from DC powerlines decreased under heavy rain conditions. The above mentioned studies and reports have concluded that under foul and wet weather conditions, the RI noise level decreased considerably. However, the RI noise level increases under fair weather conditions.

Another result of the investigations is that there is a large

effect of wind velocity on the level of RI noise. The EPRI test¹² concludes that the RI noise levels are increased by wind, with the greatest influence being when the direction of air flow is from negative to positive conductors. A wind velocity of 15 meter/second (33.3 mph) will cause an increment of about 5 dB/ μ V/m. Another report¹³ concludes that the attenuation of the RI noise level laterally from the positive conductor is not appreciably affected by conductor configuration or pole spacing.

3.2 Computation of RI Noise from DC Powerlines

To date, there are only two empirical formula developed for the calculation of RI noise from DC powerlines. One has been developed by EPRI and the other by Reiner and Gehrig¹⁴. Since EPRI is the authority on this subject matter, we will use their equation for the prediction of RI noise from DC powerlines.

The RI noise level can be calculated by

$$E = 214 \log \frac{g_{\max}}{g_0} - 278 \left(\log \frac{g_{\max}}{g_0} \right)^2 + 40 \log a \quad (3-1)$$

where: E is the RI noise level in dB/ V/m at 834 kHz and the location of the observer is at 30.5 m from the positive conductor,

g_{\max} is the maximum conductor surface gradient in kV/cm,

g_0 is the critical gradient in kV/cm,

a is the radius of subconductor in cm.

This is essentially the maximum value of the RI noise level as the equation is formulated for fair weather condition. For completeness, correction factors for frequency and radial distance are added into the above equation. Therefore, more generally

$$E = 214 \log \frac{g_{\max}}{g_0} - 278 \left(\log \frac{g_{\max}}{g_0} \right)^2 + 40 \log a + \\ 27 \log \frac{8.34}{f} + 40 \log \frac{30.5}{d} \quad (3-2)$$

where f is the frequency in kilohertz,
 d is the radial distance from the positive conductor in meters.
EPRI found g_0 to be approximately 14 kV/cm for the conductors tested.
This value will be used as a constant. For the value of g_{\max} , we will
use the equation developed by Mangoldt¹⁵. The gradient factor for the
bipolar DC powerlines is given by

$$G = \frac{1 + ((N - a) a/R)}{N a \ln \frac{2H}{R_{eq} \sqrt{\frac{(2H)^2}{S} + 1}}} \quad (3-3)$$

where G is the gradient factor in kV/cm per kV to ground,
 R_{eq} is the radius of an equivalent bundle conductor, where
 $R_{eq} = (N a R^{N-1})^{1/N}$ (3-4)
 N is the number of subconductors in the bundle,
 a is the radius of subconductor in cm,
 R is the radius of the circle on which the centres of the sub-
conductors lie with $R = (B/2)/\sin(\pi/N)$ where B is the distance
between the adjacent subconductors,
 H is the average height of conductors, defined as the minimum
height above ground plus 1/3 of the sag,
 S is the pole to pole spacing.

The maximum bundle surface gradient is thus obtained by the equation¹⁵

$$g_{\max} = G \cdot V \quad (3-5)$$

where: G is the gradient factor in kV/cm per kV to ground,

V is the line voltage to ground in kV.

EPRI has also made an observation that the RI noise levels attenuate as the square of the radial distance until it reaches an inflection point beyond which the attenuation is proportional to the radial distance. The inflection point can be approximated by the equation

$$d = \frac{\lambda}{2\pi} \quad (3-6)$$

where d is the radial distance from the positive conductor, and λ is the wavelength of the noise frequency. Beyond this point, equation (3.2) can be rewritten as

$$\begin{aligned} E = & 214 \log \frac{g_{\max}}{g_0} - 278 \left(\log \frac{g_{\max}}{g_0} \right)^2 + 40 \log a + \\ & 27 \log \frac{834}{f} + 20 \log \frac{30.5}{d} \end{aligned} \quad (3-7)$$

For illustration, some actual line designs will be considered. Table 3.1 details the line voltages and parameters. Fig. 3.1 to 3.4 show the characteristics of the calculated RI noise levels for each of the powerline designs listed in Table 3.1, at the frequencies of 200 kHz and 500 kHz with the location of the observer at various altitudes.

Line Config.	Line Voltage (\pm kV)	H(ft)	S(ft)	a (cm)	N
#1	400	63.00	34.50	3.048	1
#2	450	40.00	44.00	2.032	2
#3	600	49.87	36.75	1.525	4
#4	750	54.40	45.00	2.032	4

Table 3.1 DC line voltages and parameters considered

where: H is the average height of the conductors,
 S is the spacing between the conductors,
 a is the radius of the subconductors,
 N is the number of subconductors in a bundle.

Appendix E details program DCRI listing for the computation of the RI noise level radiating from the DC powerlines.

3.3 Prediction of Critical Distance Where the Ratio of Desired Signal/Undesired Noise is 15 dB

Similar to Section 2.4, the desired signal is the signal from the NDB transmitter (covered in Section 2.3), and the undesired signal is the RI noise from the DC powerlines dealt with in Section 3.2.

Consider the same scenario shown in Fig. 2.12 in Section 2.4.

Fig. 3.1 to 3.4 have shown that the levels of the RI noise radiated from the DC powerlines are lower than that radiated from the AC powerlines. Therefore, only line ± 400 kV which radiates highest RI noise level at higher altitudes is considered here. Fig. 3.5 and 3.6 indicate the critical distance for this line design at various receiver altitudes with the ERP of the NDB being 0.05 watt and 0.1 watt respectively.

3.4 Conclusion

As in the case of the AC powerlines, a quasi-static condition is assumed and the computation of the ratio of desired signal/undesired noise involves the magnitudes of the fields only. For illustration, Fig. 3.5 and 3.6 show the critical distances for an NDB transmitter with an ERP 0.05 watt and 0.1 watt respectively. These values of ERP are too low for any practical purposes. It can be predicted that at a higher range

of ERP values, the critical distance will reduce almost to zero. Thus if a bipolar DC powerline is located close to an NDB transmitter, the RI noise radiated by the powerline should cause no serious effect to an aircraft flying past it.

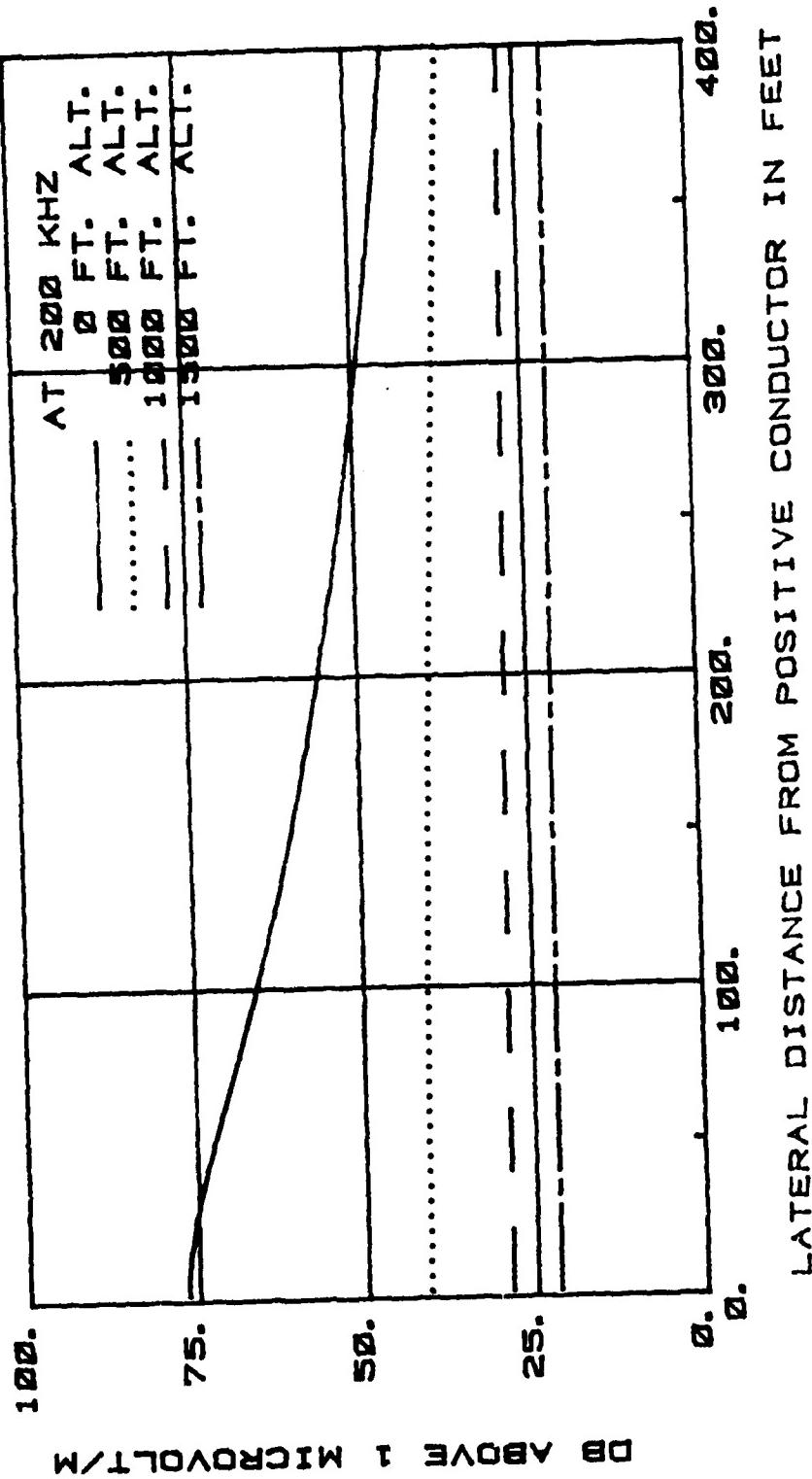


Fig. 3.1a Calculated RI noise profile for a bipolar ± 400 kV DC powerline at -30 kHz under fair weather condition.

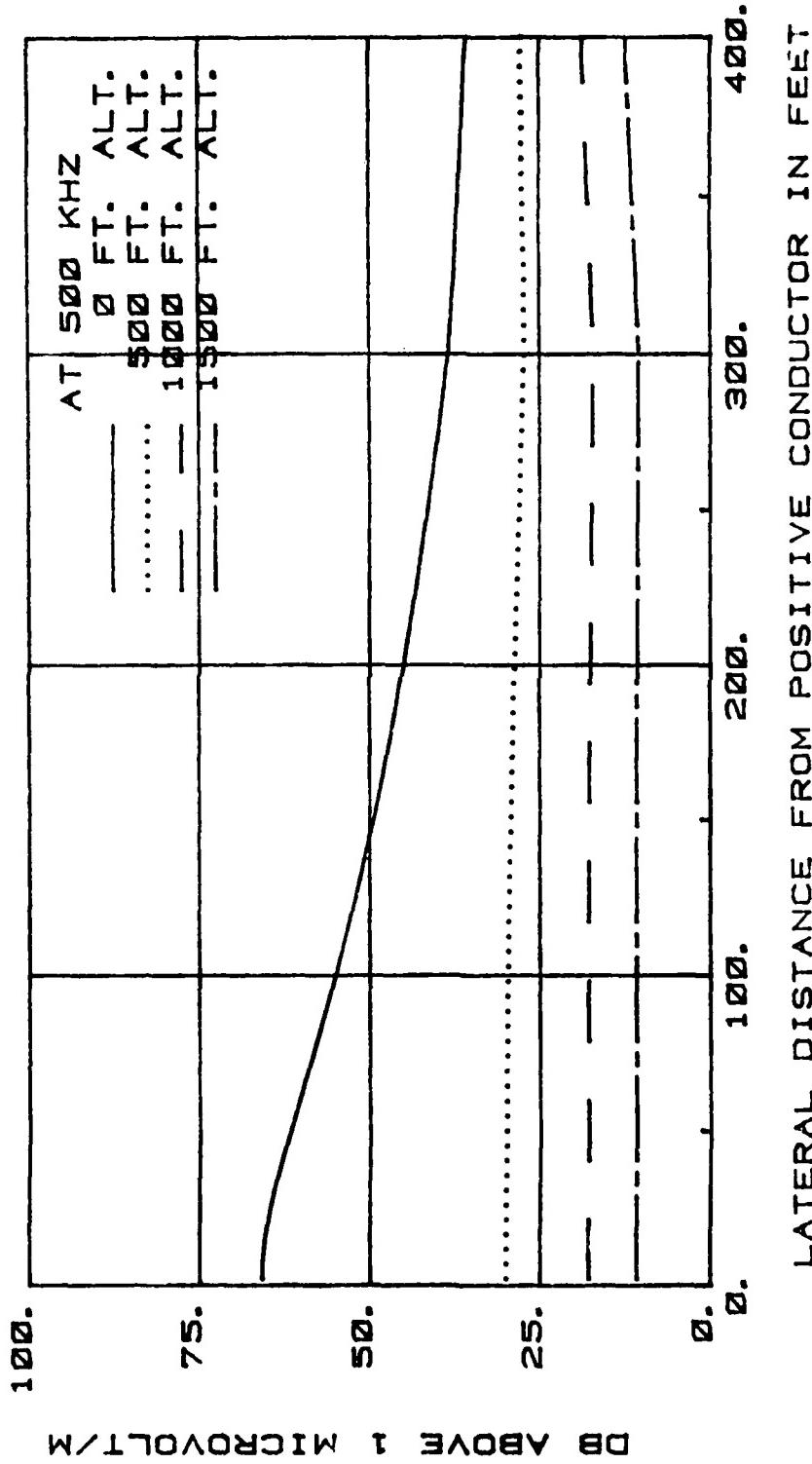


Fig. 3.1b Calculated RI noise profile for a bipolar ±400 kV DC powerline at 500 kHz under fair weather condition.

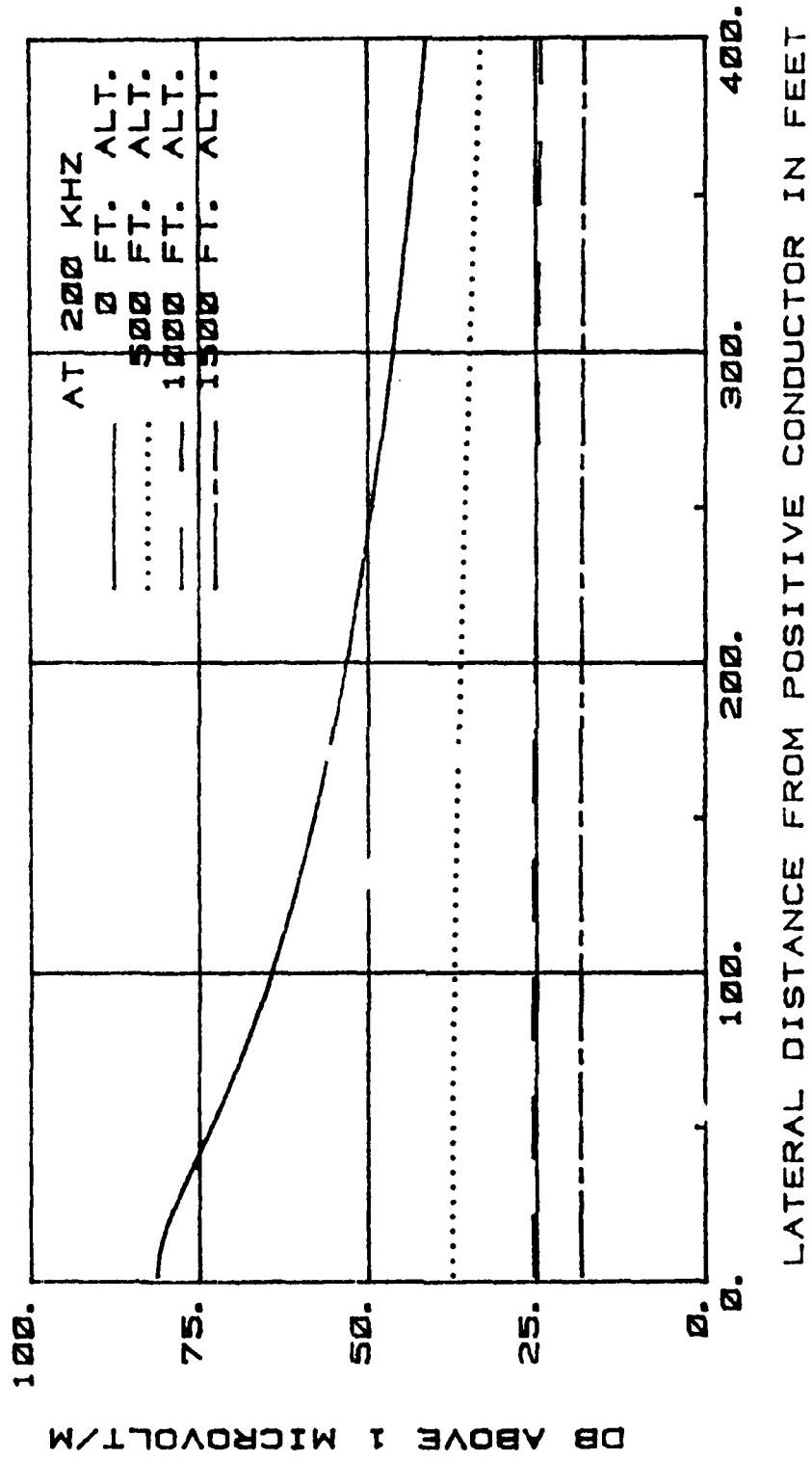


Fig. 3.2a Calculated RI noise profile for a bipolar ± 450 kV DC powerline at 200 kHz under fair weather condition.

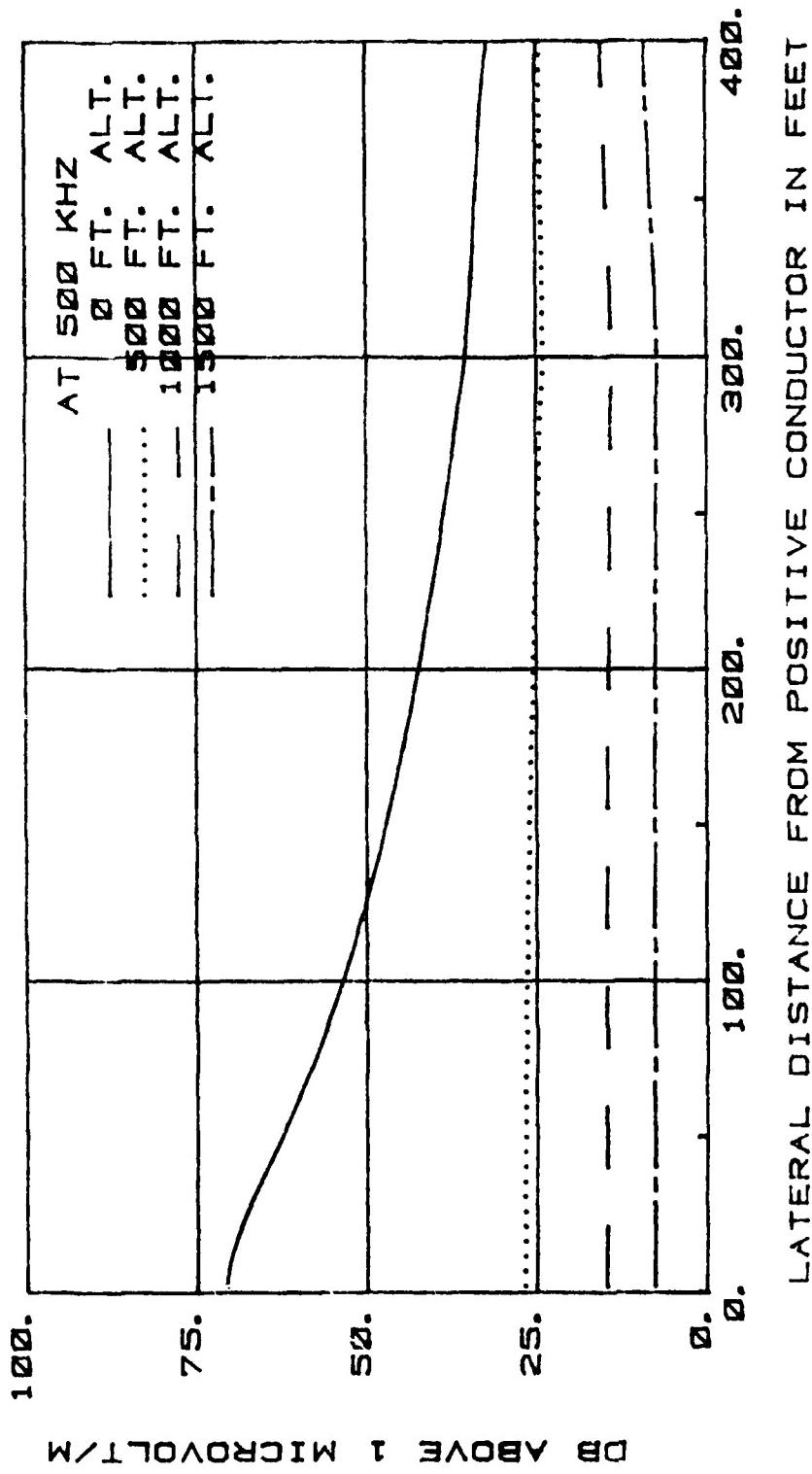
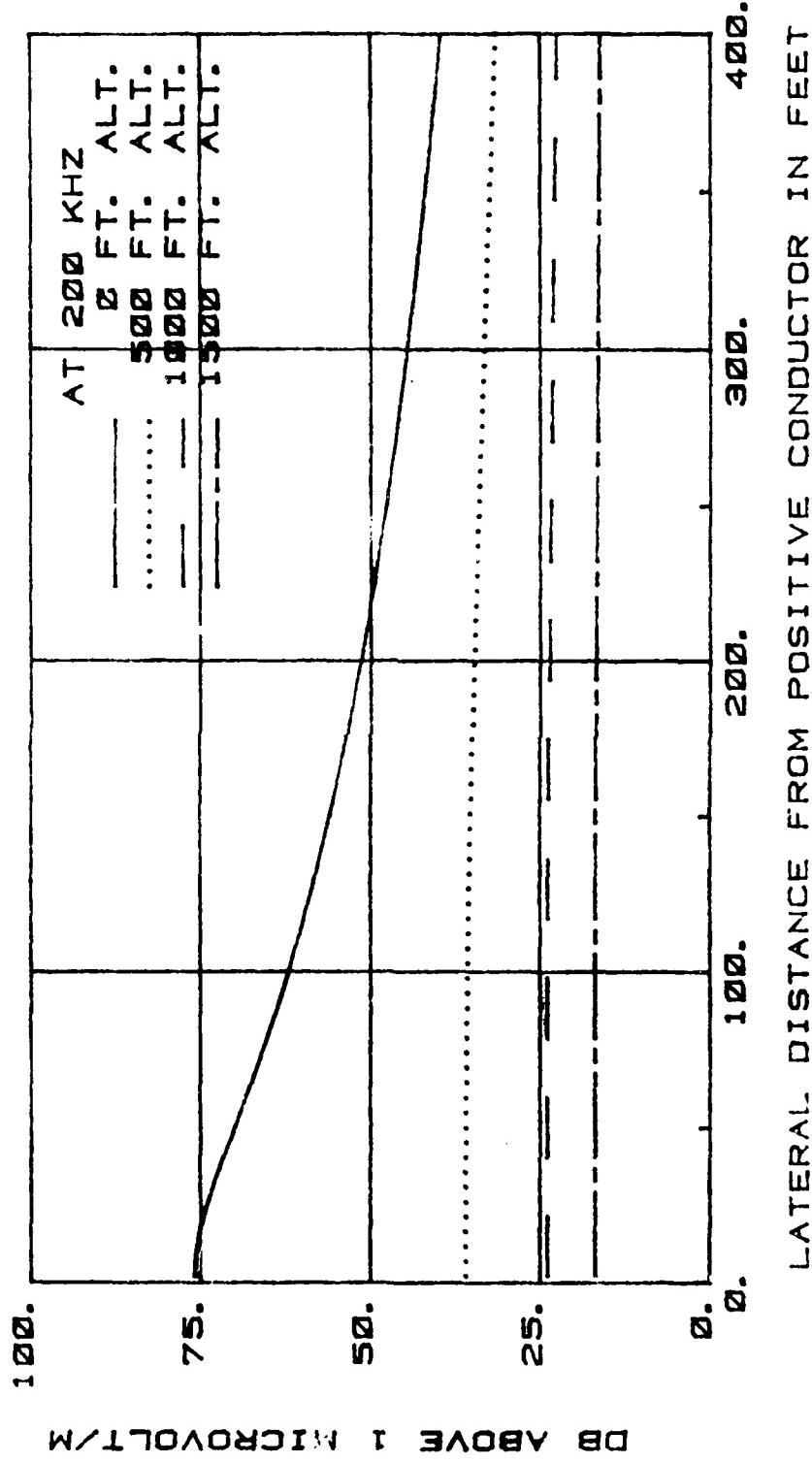


Fig. 3.2b Calculated RI noise profile for a bipolar ± 450 kV DC powerline at 500 kHz under fair weather condition.



LATERAL DISTANCE FROM POSITIVE CONDUCTOR IN FEET

Fig. 3.3a Calculated RI noise profile for a bipolar ± 600 kV DC powerline at 200 kHz under fair weather condition.

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EFFECTS OF HIGH VOLTAGE TRANSMISSION LINES ON NON-DIRECTIONAL S-ETC(U)

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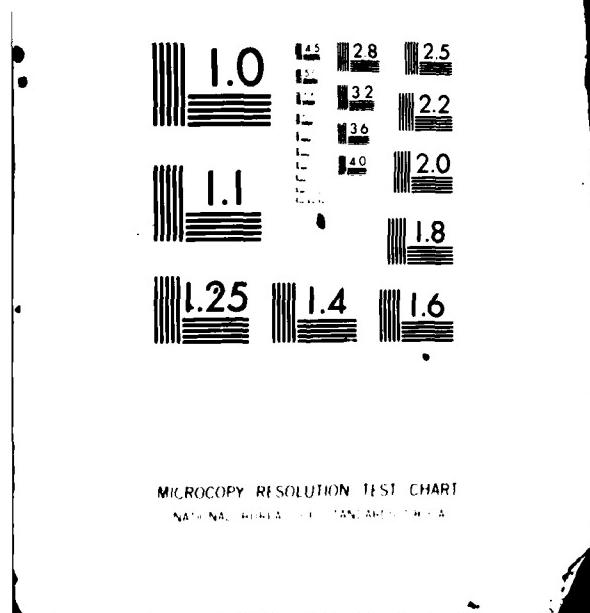
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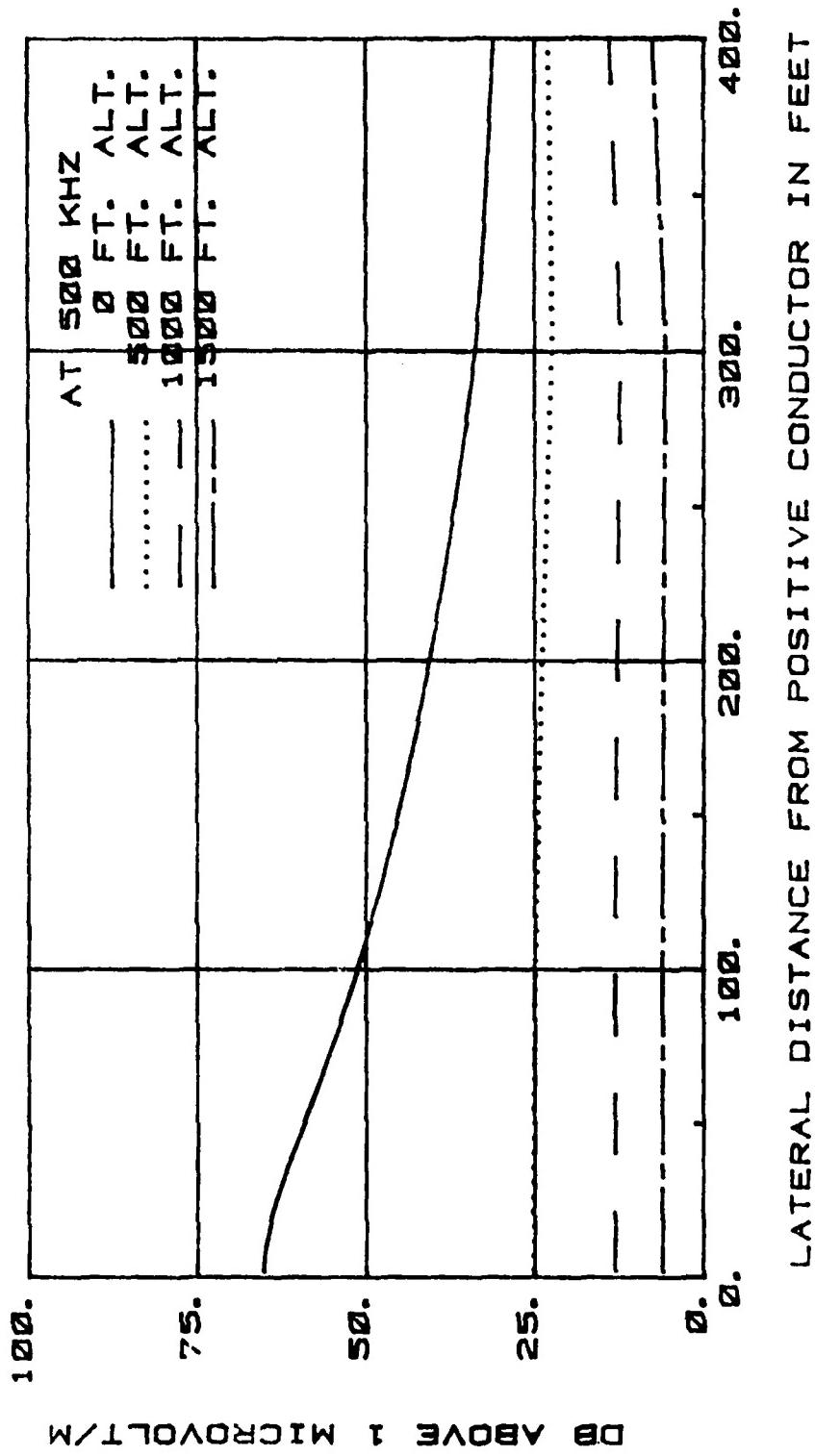


FIG. 3.3b Calculated RI noise profile for a bipolar ± 600 kV DC powerline at 500 kHz under fair weather condition.

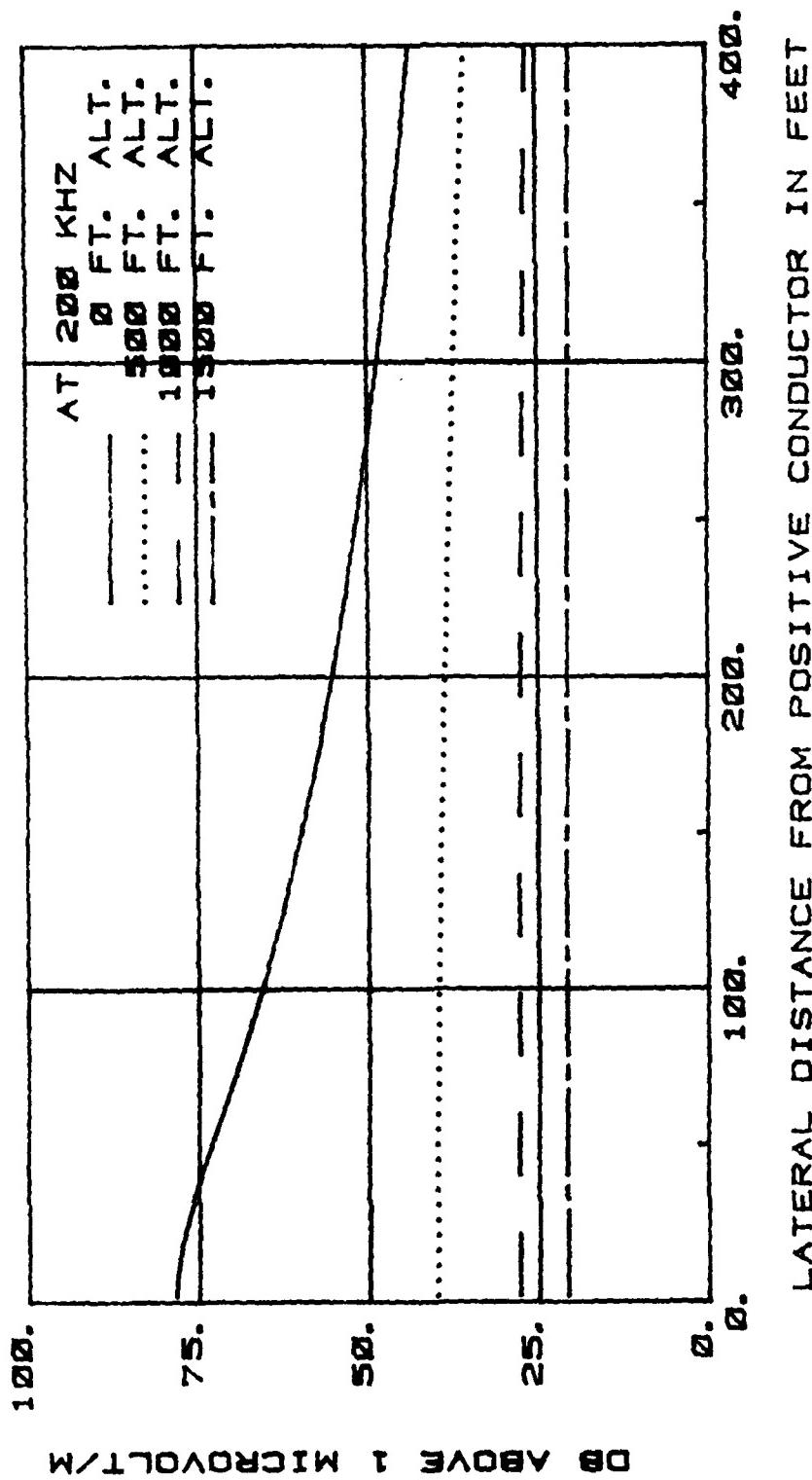


Fig. 3.4a Calculated RI noise profile for a bipolar ± 750 kV DC powerline at 200 kHz under fair weather condition.

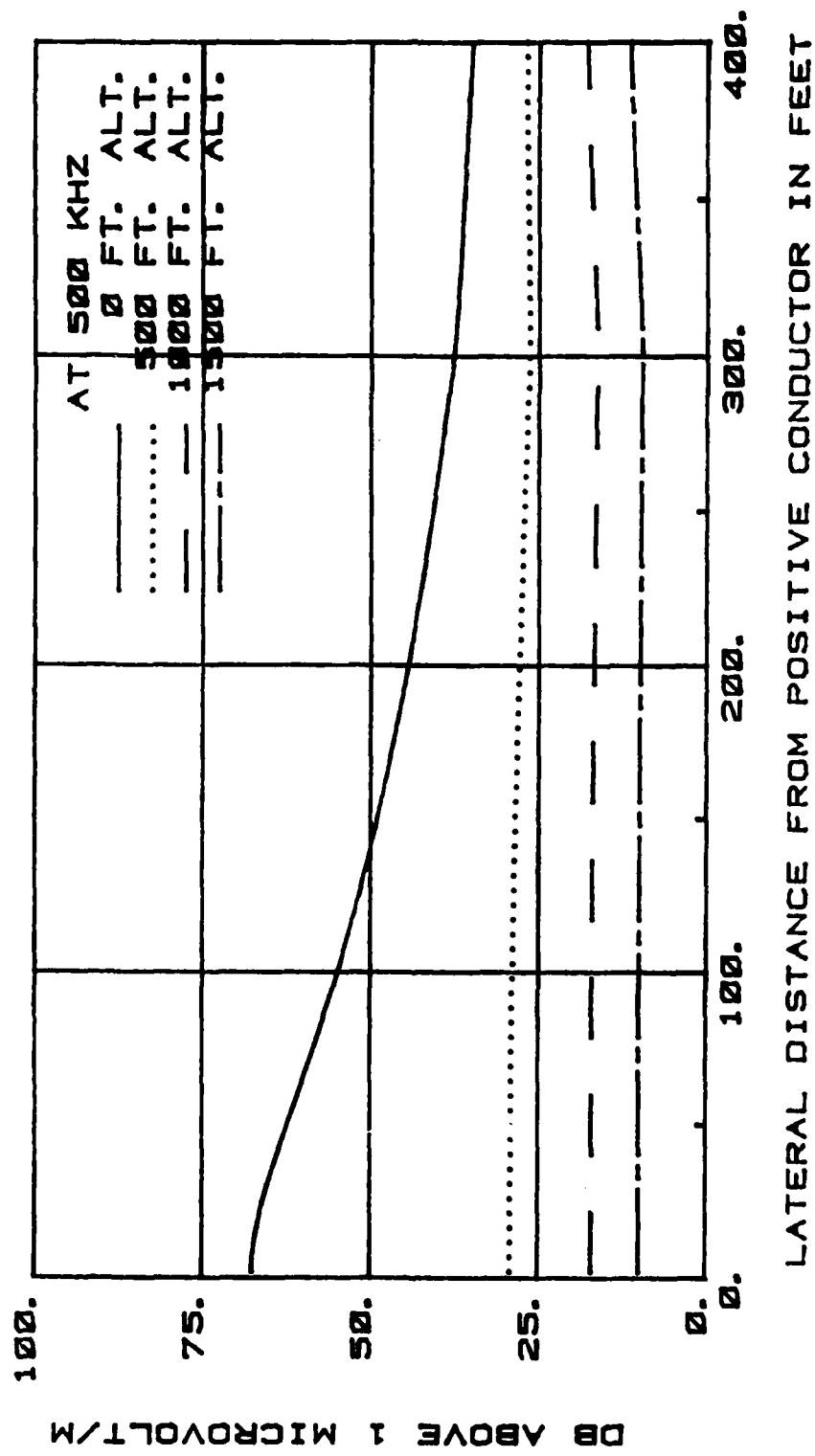


Fig. 3.4b Calculated RI noise profile for a bipolar ± 750 kV DC powerline at 500 kHz under fair weather condition.

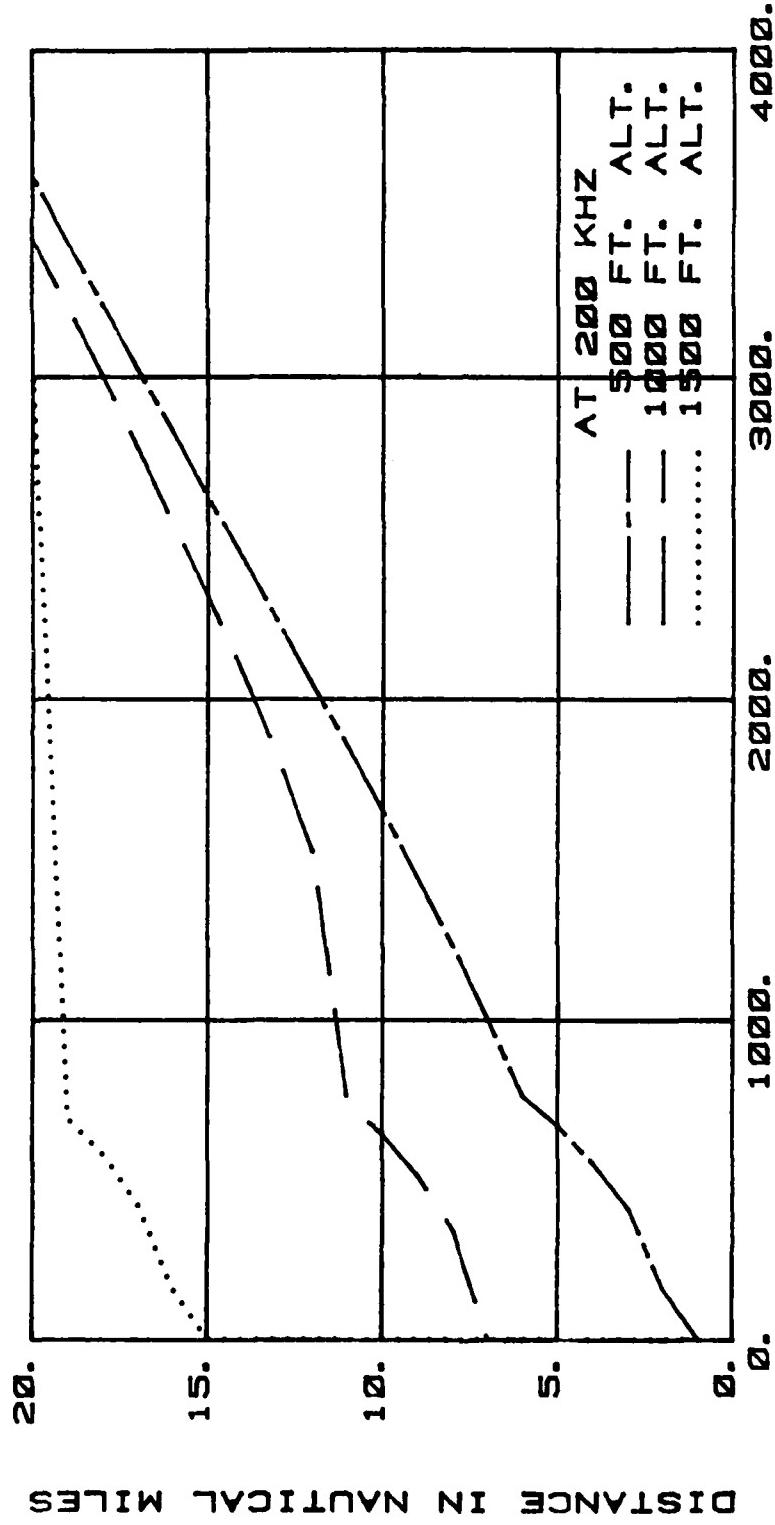


Fig. 3.5a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.05 watt, line voltage = ± 400 kV, $f = 200$ kHz, under fair weather condition.

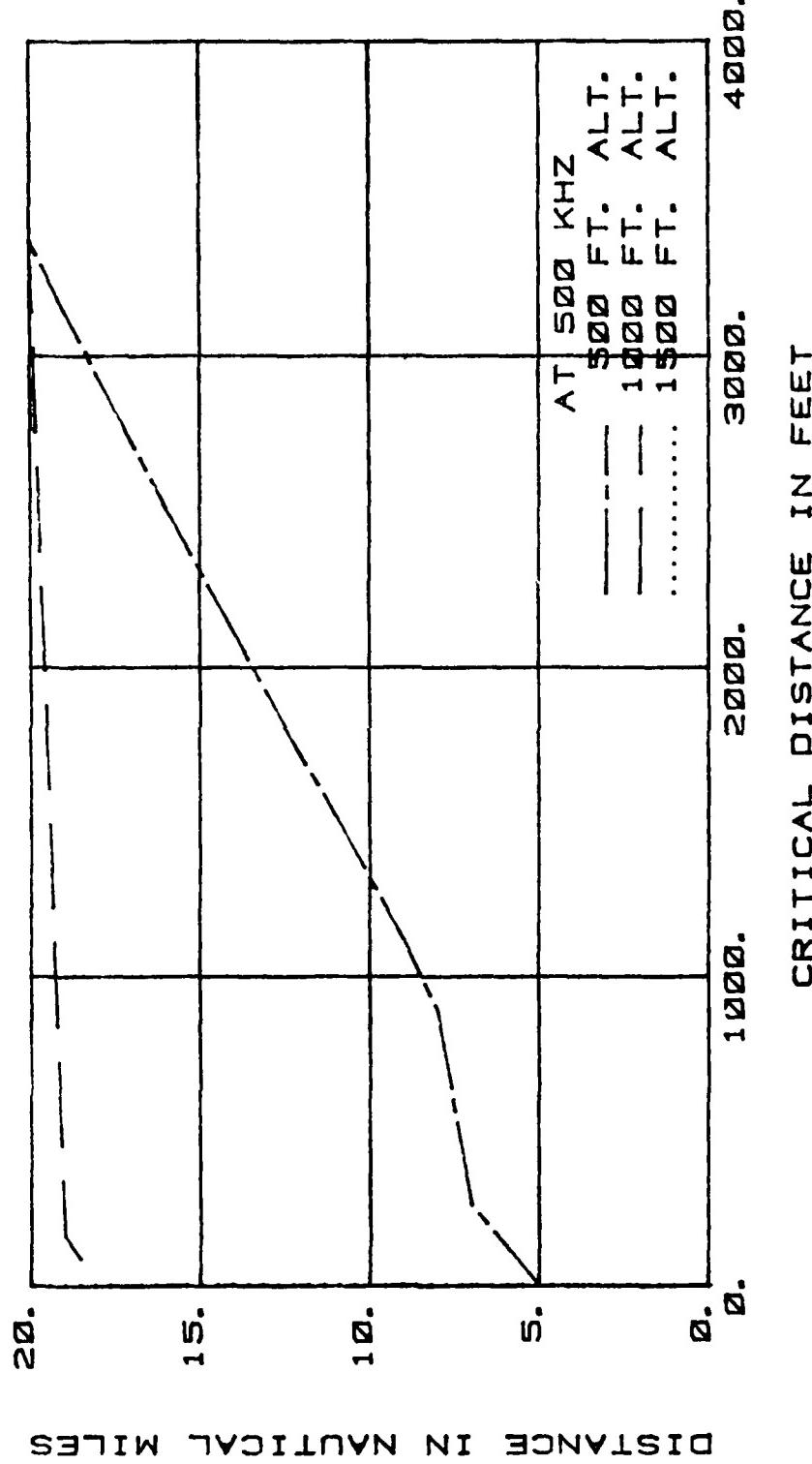


Fig. 3.5b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.05 watt, line voltage = ±400 KV, f = 500 kHz, under fair weather condition.

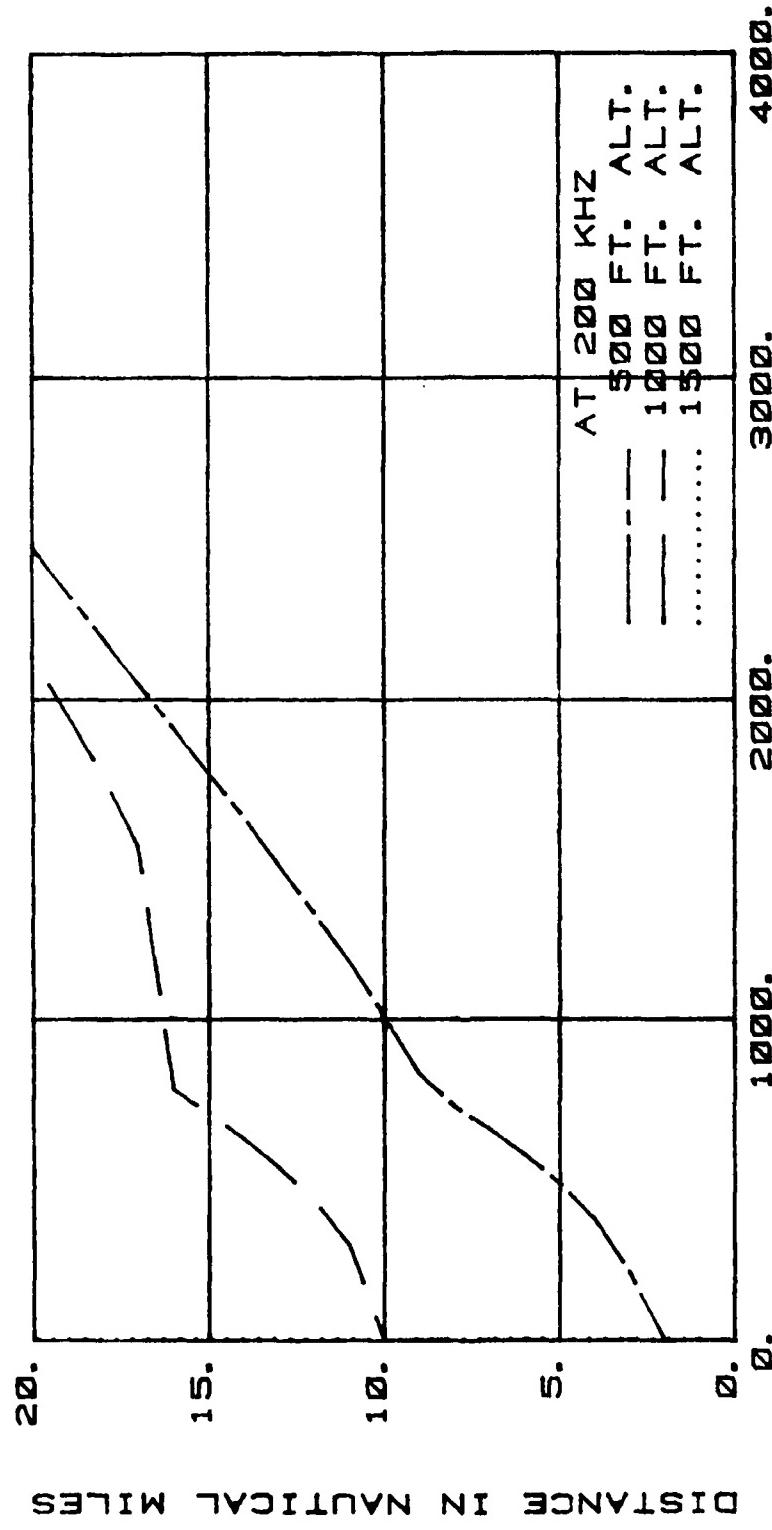


Fig. 3.6a Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = ± 400 KV, $f = 200$ kHz, under fair weather condition.

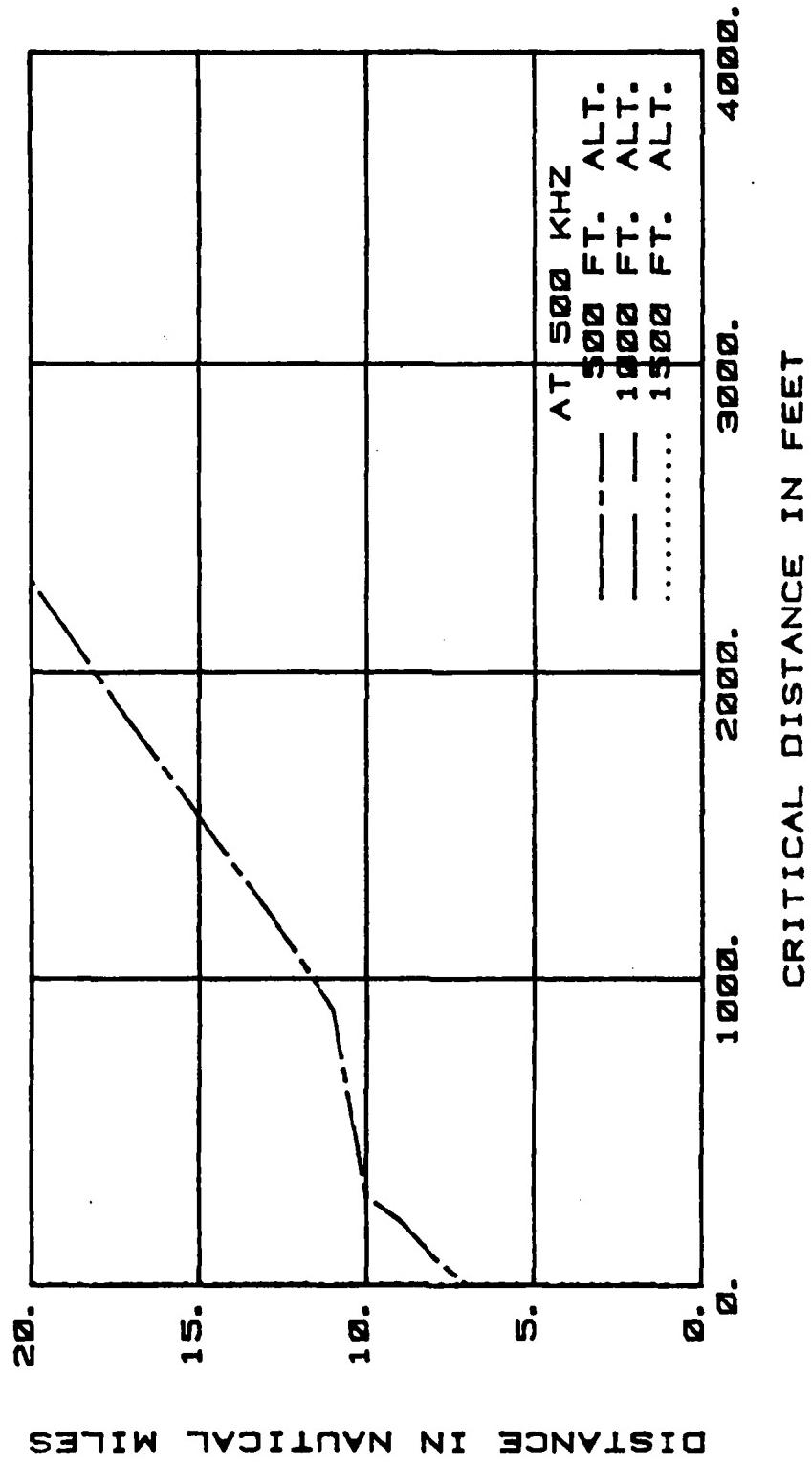


Fig. 3.6b Critical distance from aircraft to powerline for 15 dB s/n ratio as a function of aircraft altitudes and distance from NDB transmitter to powerline; ERP = 0.1 watt, line voltage = ± 400 KV, $f = 500$ kHz, under fair weather condition.

Chapter IV

RERADIATION PREDICTION FROM POWER-LINE STRUCTURES

4.1 Introduction

In order to provide predictions of the possible effects on NDB reception of signals reradiated by large conducting objects, such as power transmission lines, accurately and economically a large scale series of measurements is not feasible. In order to provide a large enough data base for meaningful conclusions a great many airborne measurements of field strength would need to be made. Furthermore, actual sites which would provide suitable situations regarding the relative locations of an NDB and large power line structure would have to be located.

Fortunately, there has been considerable progress made recently in the application of computers to electromagnetic problems. More specifically, techniques have been developed which enable the calculation of induced currents and the resulting reradiated fields on wire structures caused by incident electromagnetic energy provided that the wire structures are small in comparison to the wavelength of the incident field. Since NDB frequencies are so low, even very large mechanical structures, such as sections of power transmission lines, are small in comparison to the NDB wavelengths.

Since these computer techniques have not been previously applied to the situations we are here concerned with, a validation by comparison with measurement seemed appropriate. Measuring the reradiated fields from an actual power line, however, would not be possible due to the

very complex geometry of the structure. Instead, a radio tower has been used for the validation. Since the source of reradiation from a straight vertical tower is localized, the reradiated fields can be measured by using a loop receiving antenna and orienting the loop so as to null the signal coming directly from the NDB. If the geometry is chosen suitably, the loop may simultaneously be oriented so as to, at least approximately, respond maximally to the reradiated fields coming from the tower. A suitable tower is one owned by radio station WRFD in Columbus, Ohio. It is a straight tower 558 feet high. The NDB transmitters in the vicinity are CMH and DKG. The former is operating at 391 KHz with an effective radiated power of 9.683 watts and the latter at 348 KHz with an ERP of 0.6 watt. Fig. 4.1 is a map showing the locations of the tower and the NDB transmitters. The CMH antenna is situated at about 11.72 NM S-23°-E of the tower and that of DKG is at about 5.86 NM S-27°-W. A sketch map is illustrated in Fig.

4.2.

4.2 Measured Results

Measurements were taken along the access road leading to the tower. Equipment used included Interference Analyzer Model EMC-25, Remote Vertical Antenna Model RVR-25 and Remote Loop Antenna Model ALR-25. Measurements were made at five different places along the access road as indicated by Fig. 4.3. In each case the vertical or loop antenna was mounted on a five-foot high tripod.

Results obtained were the total electric field strength as measured by the vertical antenna and the magnetic field strength as measured by the loop antenna. When using the loop antenna two measurements

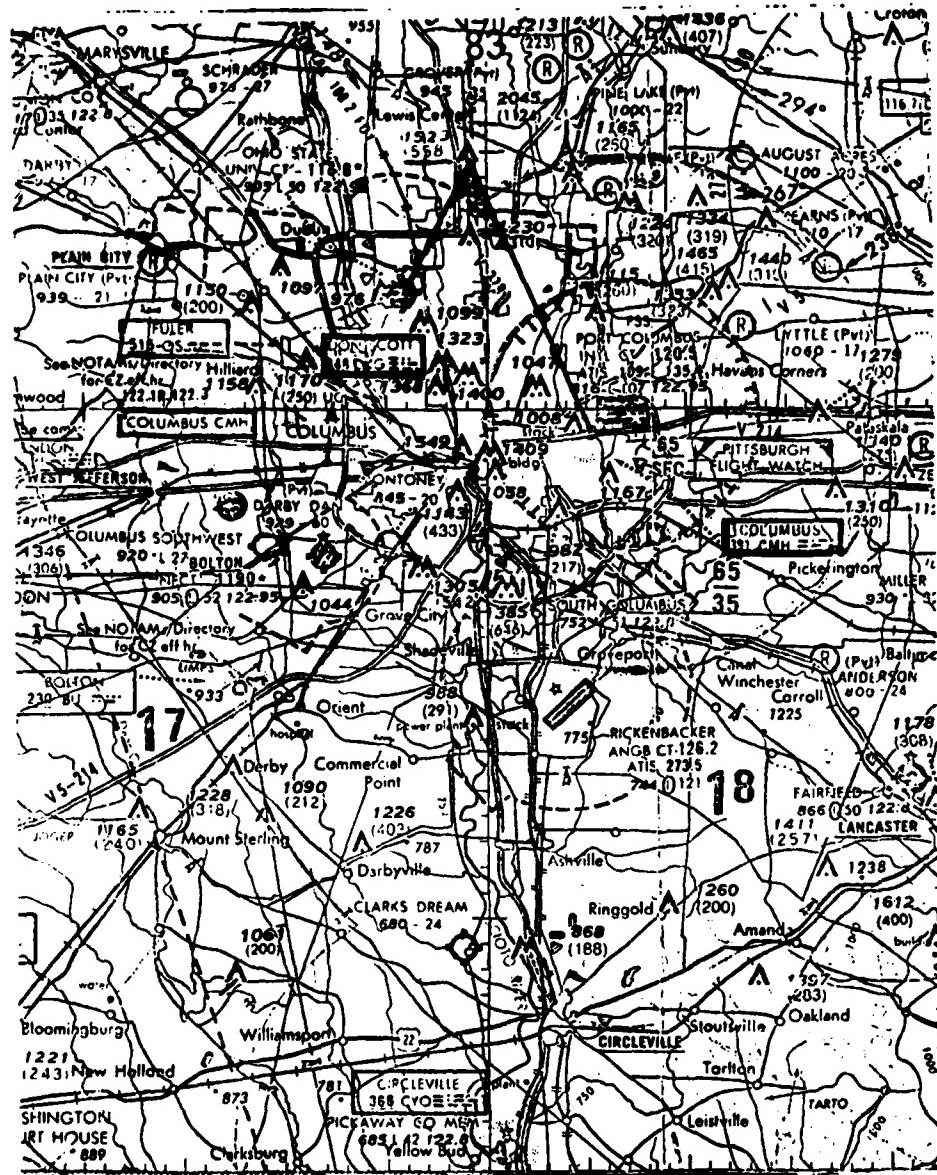


Fig. 4.1 Map showing the location of the radio tower and the CMH and DKG transmitters in the Columbus area.

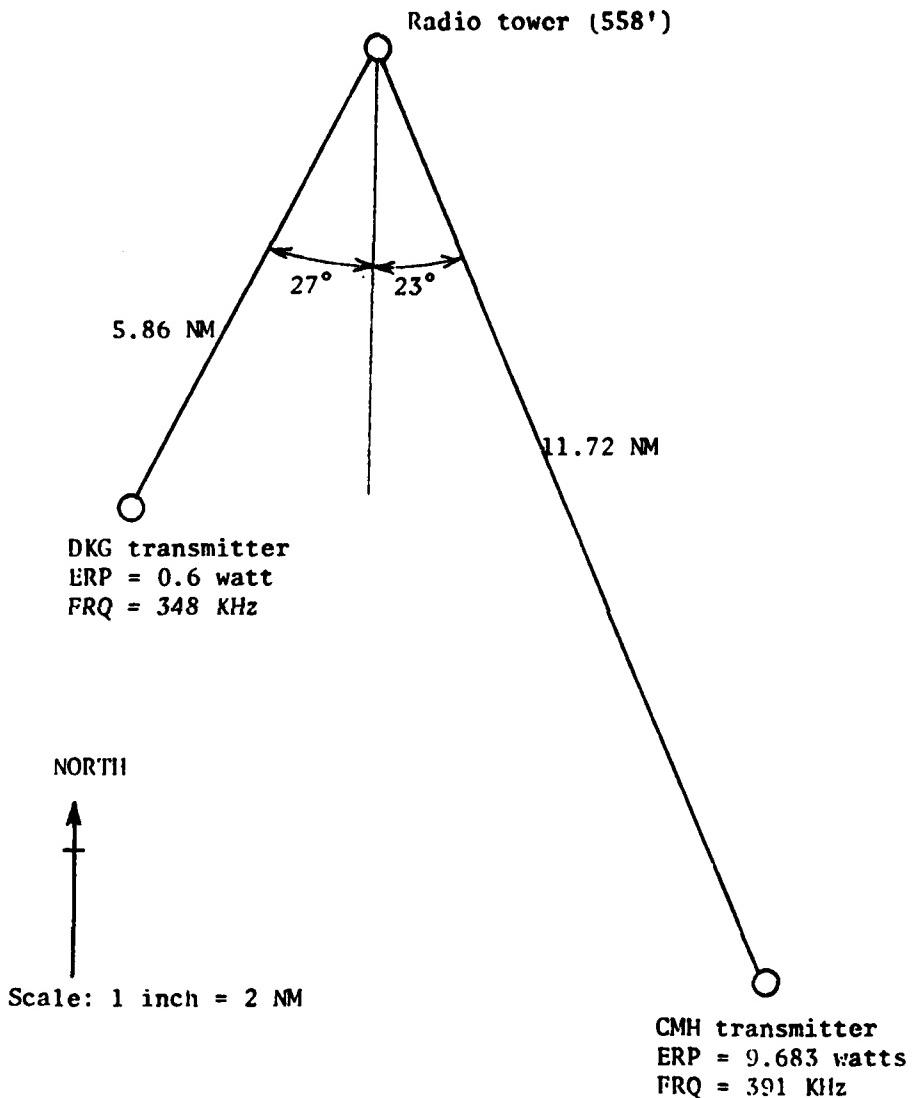


Fig. 4.2 Sketch of the location of radio tower with respect to the CMH and DKG transmitters.

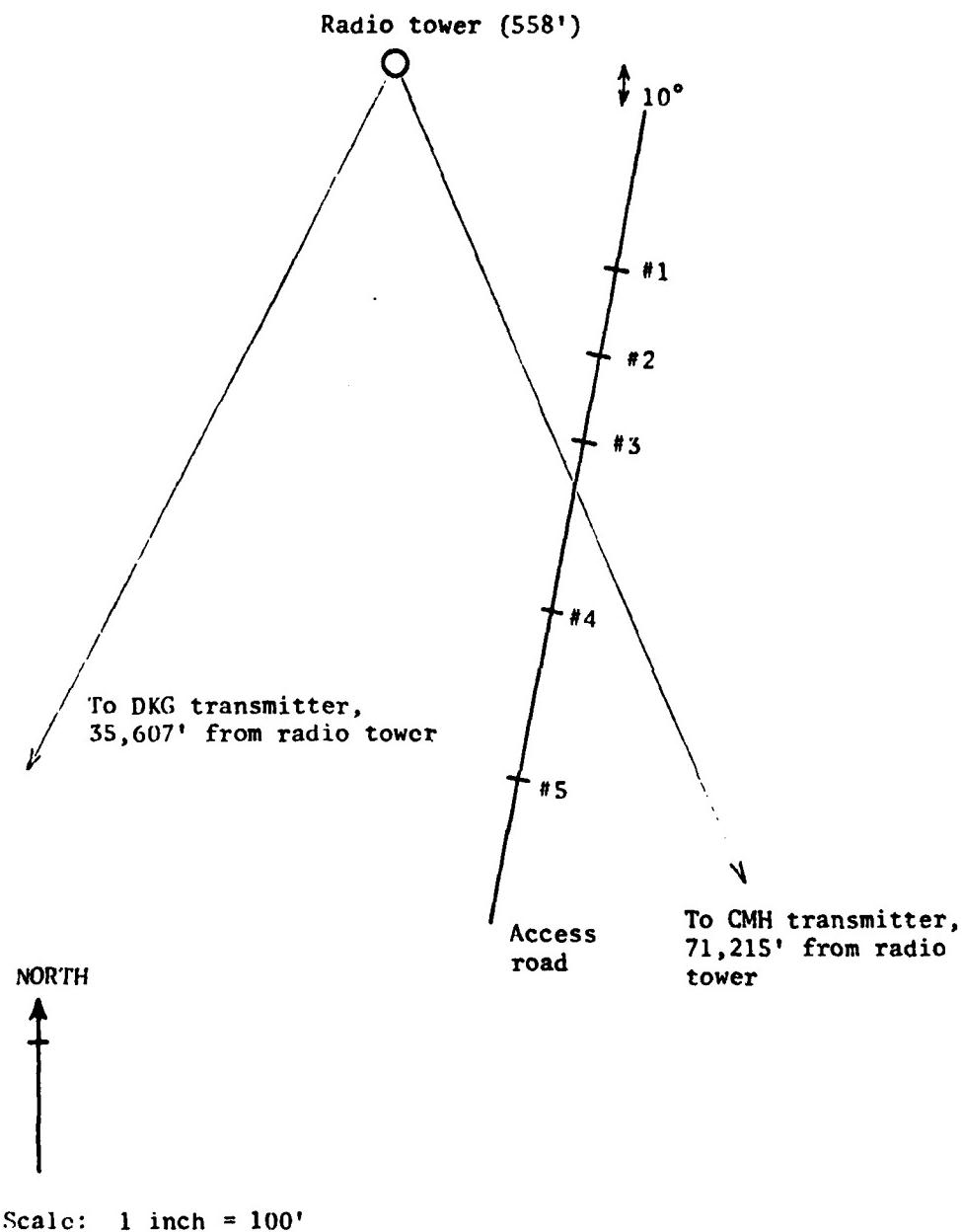


Fig. 4.3 Sketch of the locations of five measuring points with respect to the radio tower and the NDB transmitters.

were made. The loop was rotated in a vertical plane, and the maximum and minimum values of the magnetic field were measured. The maximum value was considered to be primarily due to direct radiation from the NDB, and is denoted the "direct" magnetic field. The total electric and direct magnetic measured fields are listed in Tables 4.3 and 4.4.

4.3 Calculated Results

The calculated results are obtained by using a computer program based on the work of Richmond¹⁵. The program makes use of a mathematical model of the NDB transmitting antenna and the radio tower to compute the electric-field strength for any location. The ground is assumed flat and perfectly conducting, as the major interest is the reradiated signal.

Essentially, the purpose of this preliminary work is to check the accuracy and reliability of using this particular computer program to predict signal reradiation. The test involves comparison of the measured results and the calculated results that are obtained by using the mathematical models that simulate the same physical situation.

The coordinates of the five measuring locations with respect to each transmitting antenna are shown in Tables 4.1 and 4.2. In each case the x-axis is the imaginary line that passes through the NDB antenna and the reflecting tower with the former being the origin. The electric field strength of the direct signal from the NDB transmitters, the reradiated signal from the tower and the total electric-field strength are calculated along the access road with respect to CMII and DKG. These are illustrated in Fig. 4.4 and 4.5. In addition, Fig. 4.6 shows the calculated behavior of the total electric-field

Location	x-coordinate (feet)	y-coordinate (feet)	z-coordinate (feet)
# 1	71,065.0	-71.7	5.00
# 2	71,020.0	-42.3	5.00
# 3	70,980.0	-16.1	5.00
# 4	70,895.0	39.6	5.00
# 5	70,815.0	92.0	5.00

Table 4.1. Coordinates with respect to CMH transmitter.
The x-axis originates at the NDB and passes through the reflecting radio tower.

Location	x-coordinate (feet)	y-coordinate (feet)	z-coordinate (feet)
# 1	35,557.0	-168.0	5.00
# 2	35,509.5	-185.6	5.00
# 3	35,462.0	-203.2	5.00
# 4	35,367.0	-238.3	5.00
# 5	35,269.5	-274.4	5.00

Table 4.2. Coordinates with respect to DKG transmitter.
The x-axis originates at the NDB and passes through the reflecting radio tower.

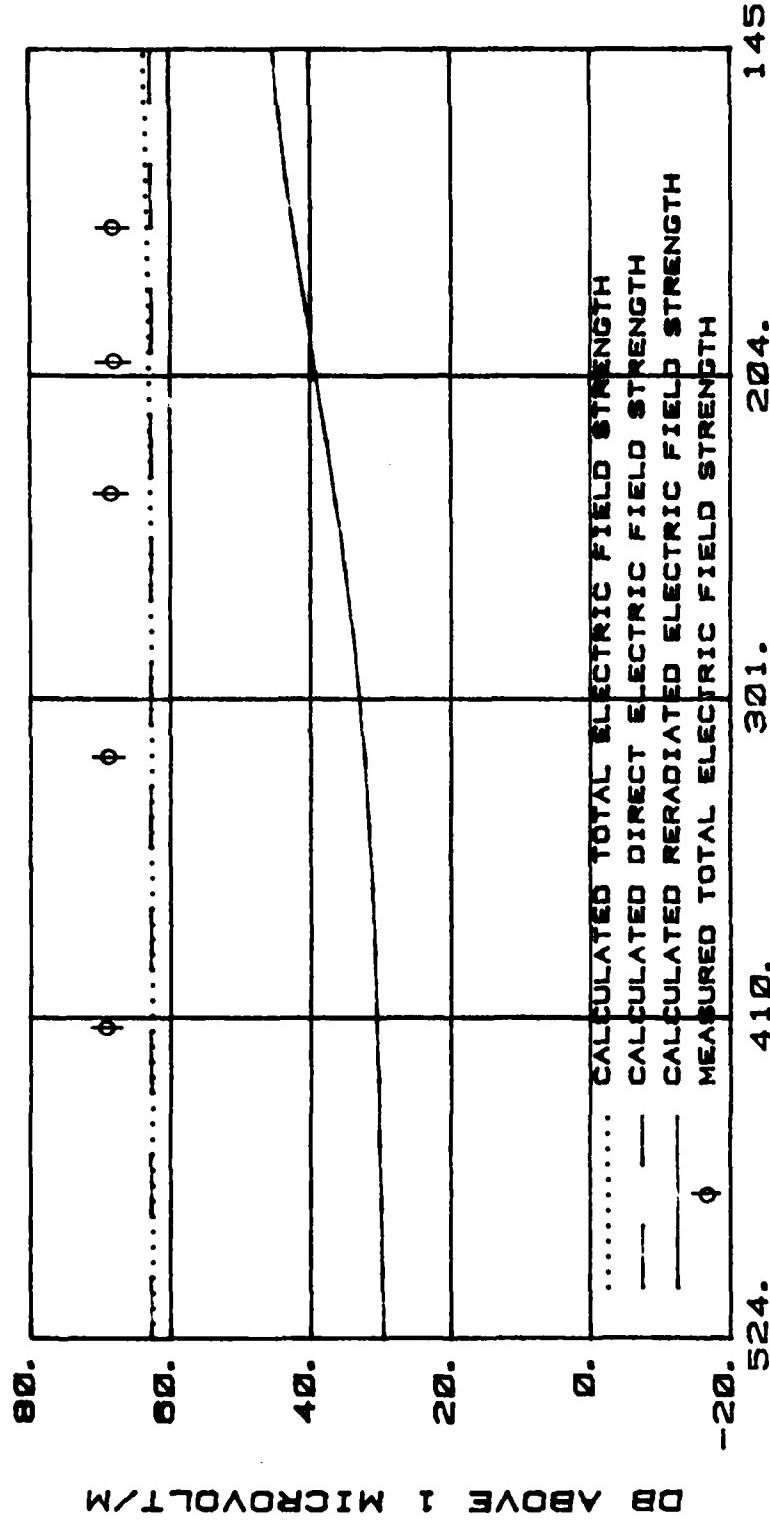
along the x-axis for +300 feet from the tower for the CMH transmitter.

Fig. 4.7 illustrates the similar characteristics for the DKG transmitting antenna. In both cases the curves are smooth as expected and the total electric-field strength levels increase at points closer to the tower due to the fact that the reradiated signal strength is higher in this region. The peak value of the tower electric-field strength that coincides with the location of the tower should be ignored as this value is not valid. The computer model cannot handle points inside a conductor.

4.4 Comparison of the Measured and Calculated Results for Direct and Total Fields

Measured results obtained by using the vertical antenna are compared with the calculated total electric-field strength. Fig. 4.4a and 4.5a show the levels of the total electric-field strength for the CMH and DKG transmitting antenna respectively, and comparison between the measured and calculated results can be made directly. For convenience, Tables 4.3 and 4.4 provide the comparison for the five measuring locations.

In the calculated results, the electric-field strength of the direct signal from the transmitting antenna could be converted to a magnetic-field strength by using the equation $\eta = E/H$, when η is the intrinsic impedance of the medium and could be assumed to be approximately 120 . The measured levels of the magnetic-field strength (with loop oriented for maximum signal) for the CMH and DKG transmitters are also shown in Fig.4.4b and 4.5b respectively. Comparisons are given as well in Tables 4.5 and 4.6.



RADIAL DISTANCE FROM RADIO TOWER IN FEET

Fig. 4.4a Calculated and measured values of electric field strength along the access road with respect to CMH transmitter.

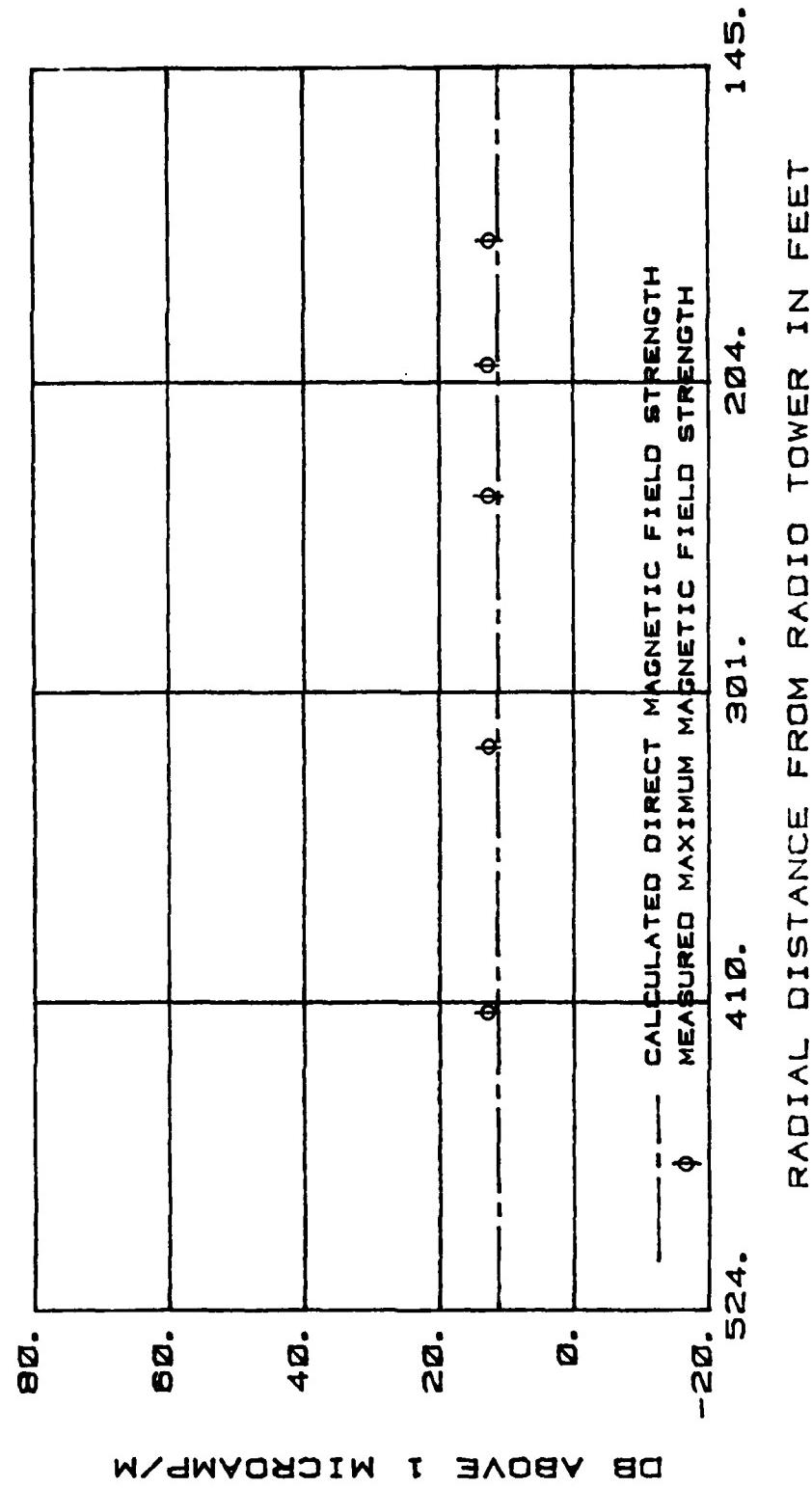


Fig. 4.4b Calculated values of radiated magnetic field strength and measured maximum magnetic field strength along the access road with respect with CMH transmitter.

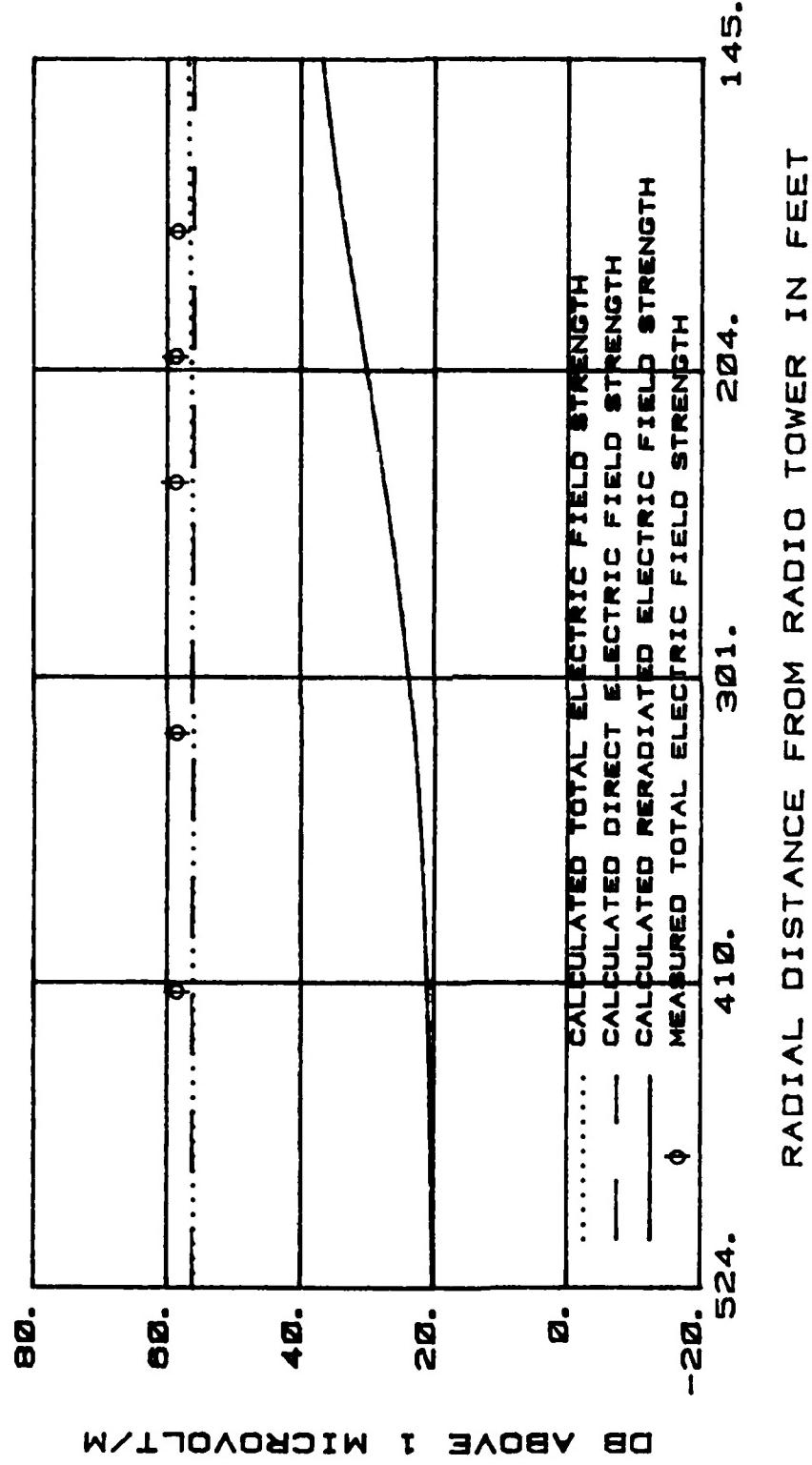


Fig. 4.5a Calculated and measured values of electric field strength along the access road with respect to DKG transmitter.

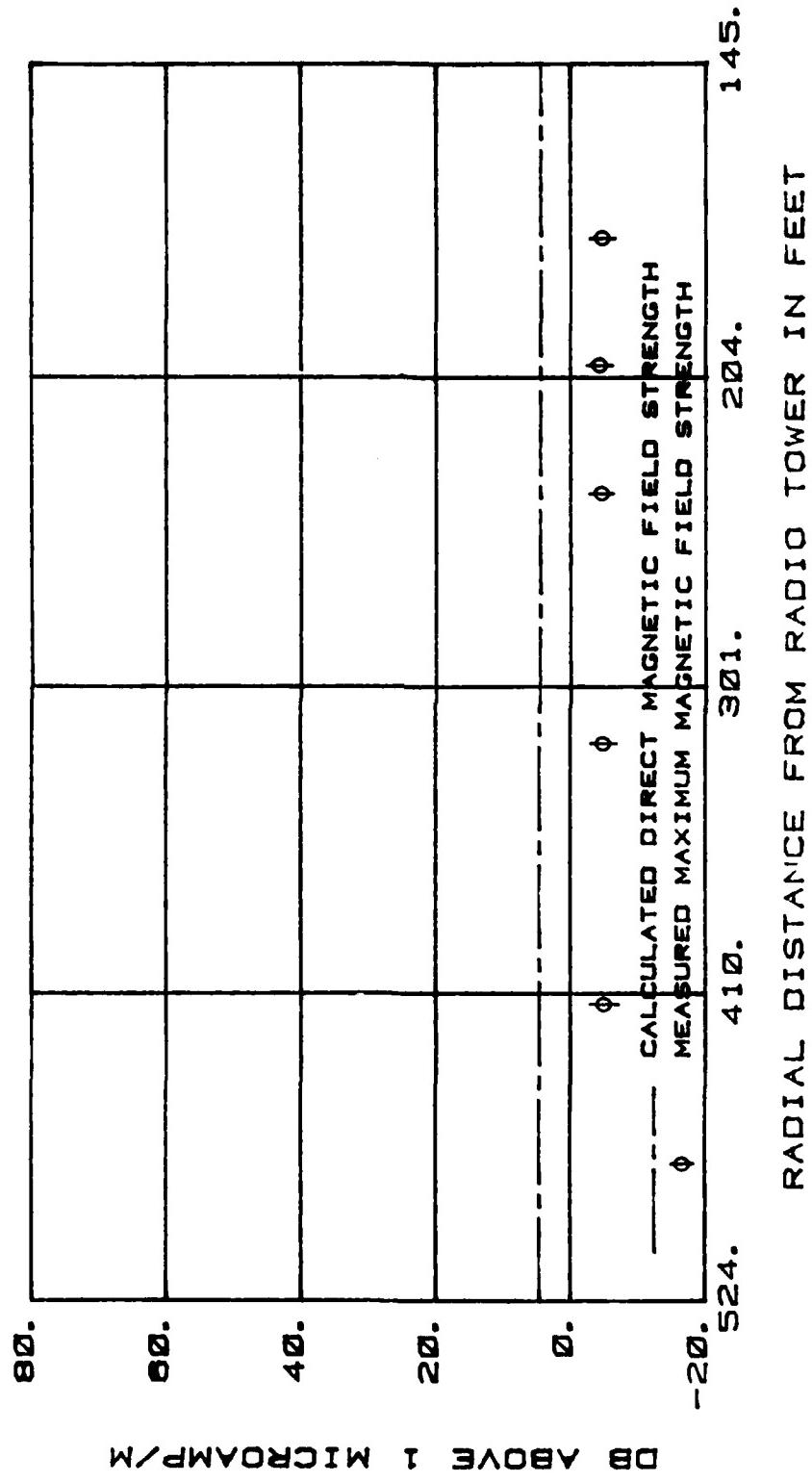


Fig. 4.5b Calculated values of radiated magnetic field strength and measured maximum magnetic field strength along the access road with respect with DKG transmitter.

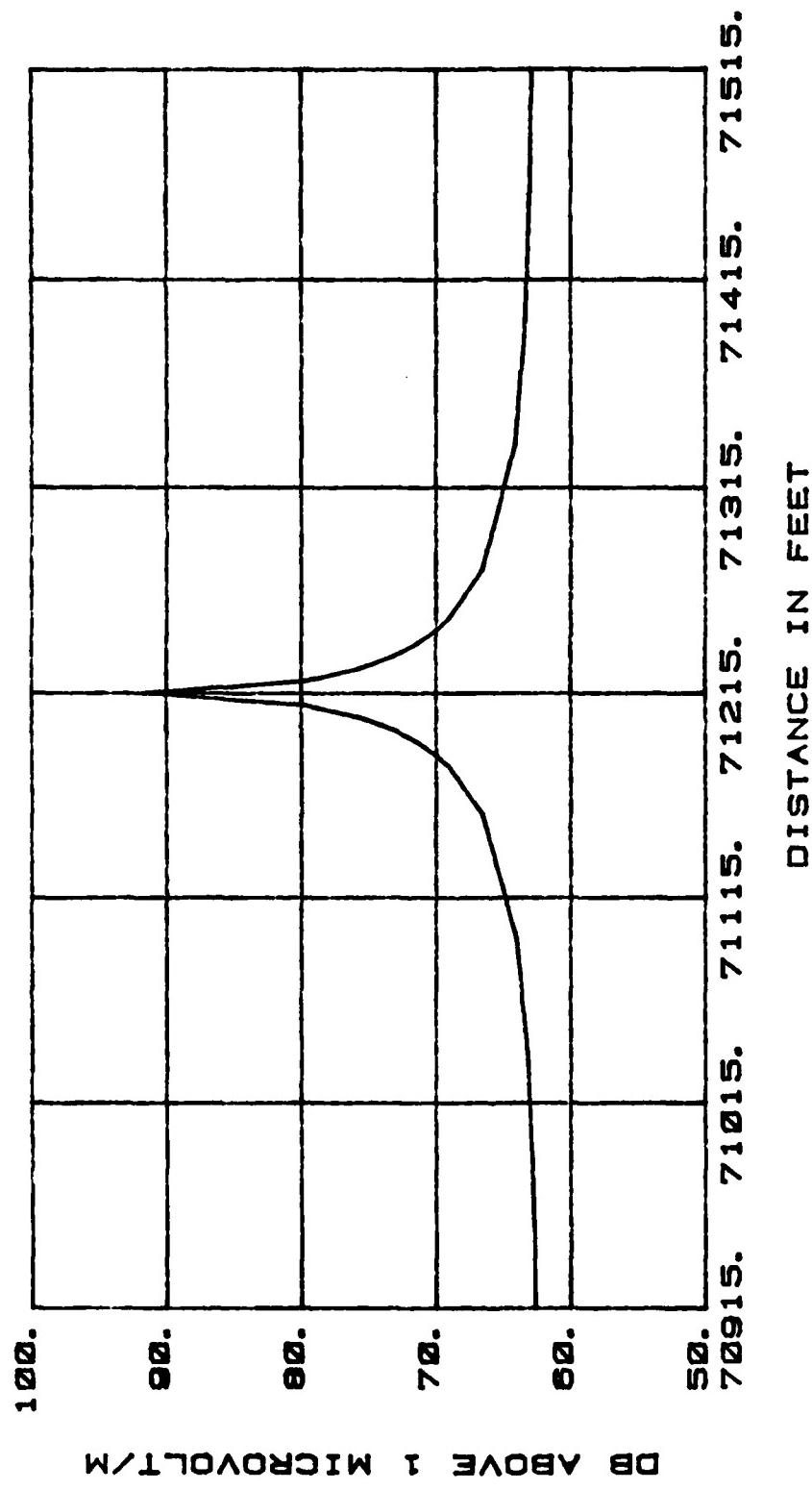


Fig. 4.6 Calculated values of the total electric field strength with respect to CMH transmitter along the x-axis, originating at the NDB antenna and passing through the tower.

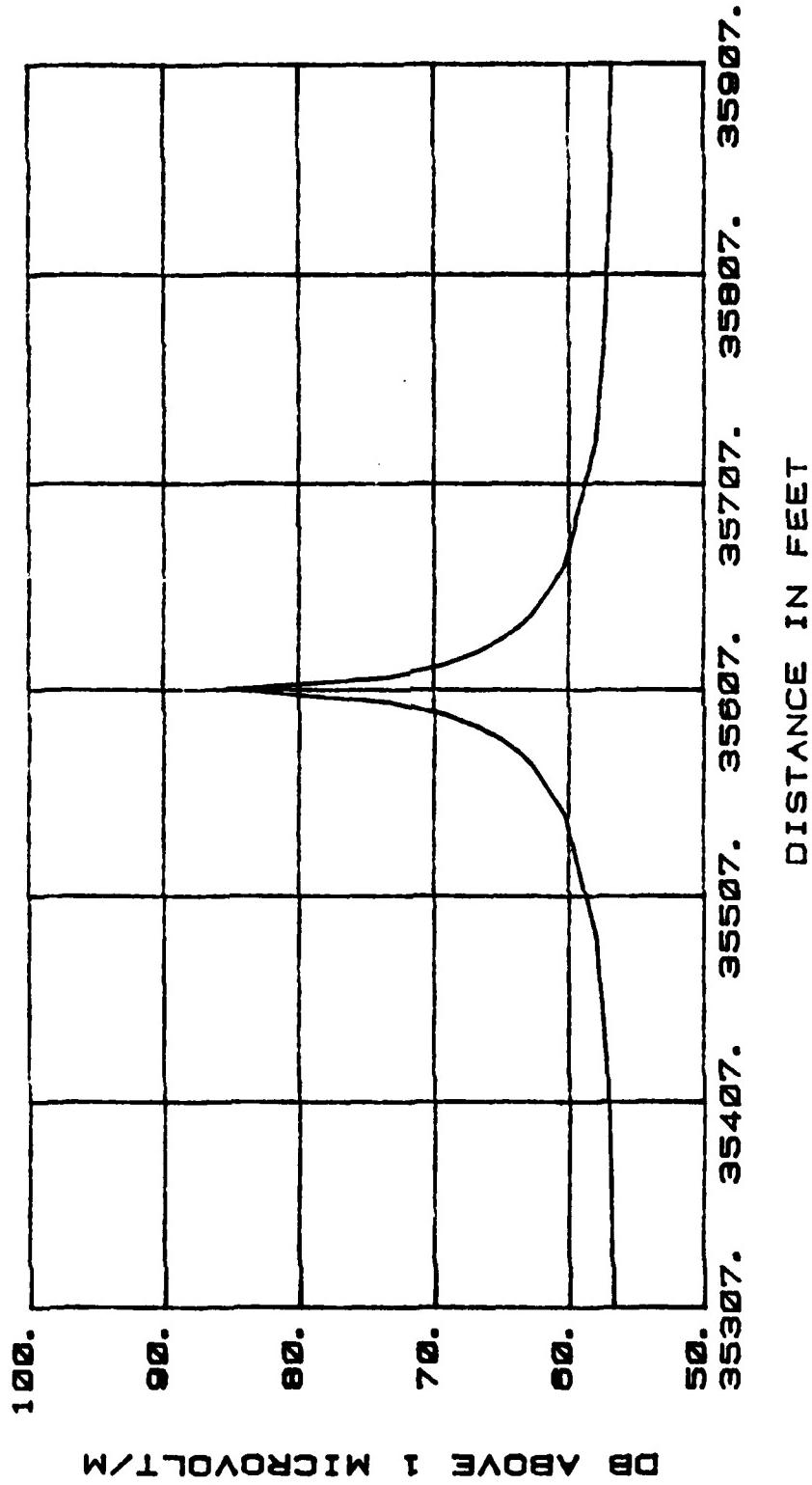


Fig. 4.7 Calculated values of the total electric field strength with respect to DKG transmitter along the x-axis, originating at the NDB antenna and passing through the tower.

Location	Measured Results (dB/ μ V/m)	Calculated Results (dB/ μ V/m)	Difference (dB/ μ V/m)
# 1	69.6	63.3	6.3
# 2	68.6	63.0	5.6
# 3	68.6	62.8	5.8
# 4	68.6	62.6	6.0
# 5	68.6	62.5	6.1

Table 4.3. Total electric-field strength comparison for CMII transmitter. Measurements made using vertical monopole antenna

Location	Measured Results (dB/ μ V/m)	Calculated Results (dB/ μ V/m)	Difference (dB/ μ V/m)
# 1	59.8	57.30	2.50
# 2	59.8	57.05	2.75
# 3	59.8	56.90	2.90
# 4	59.3	56.70	2.60
# 5	58.8	56.65	2.15

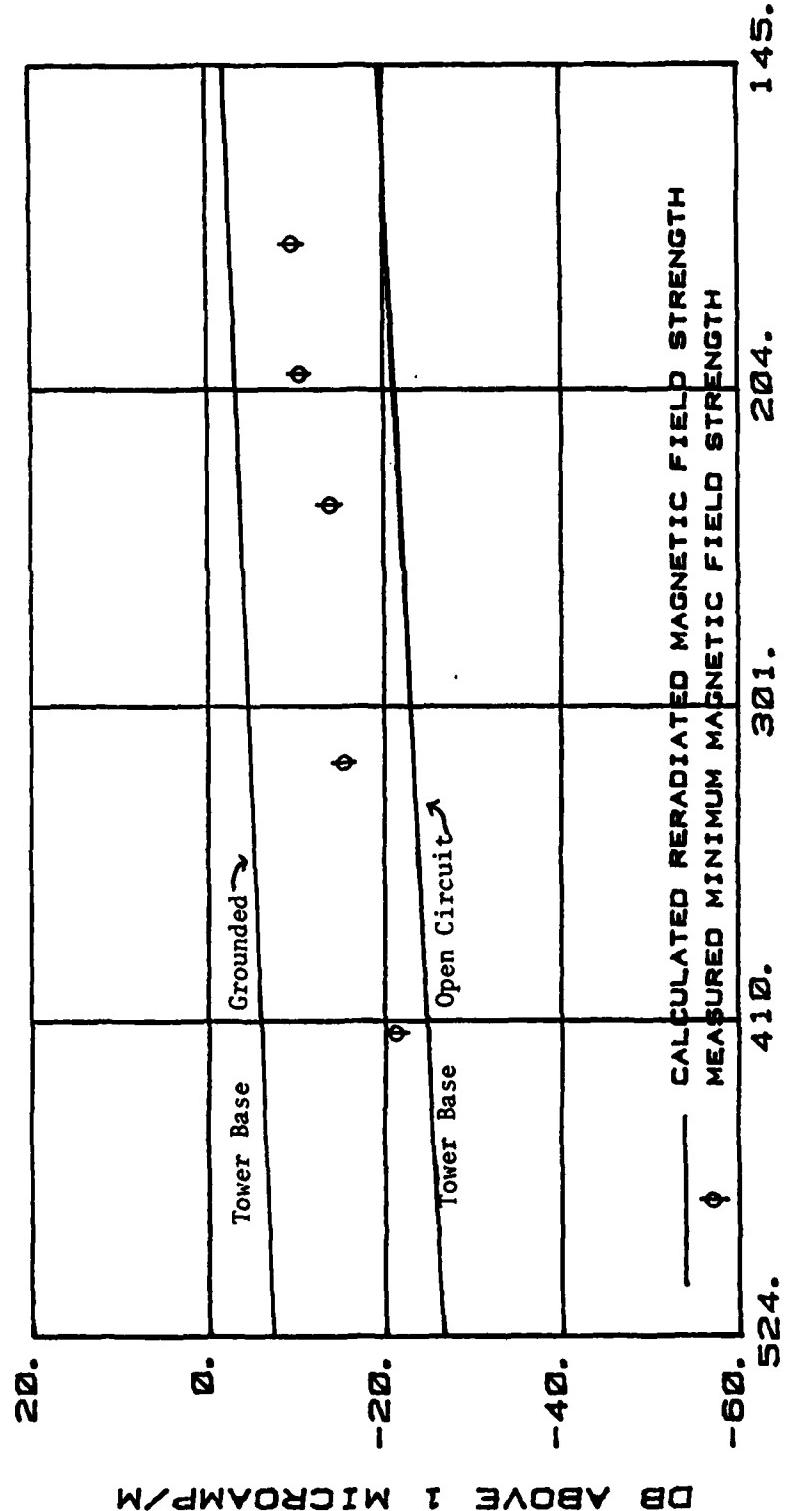
Table 4.4. Total electric-field strength comparison for DKG transmitter. Measurements made using vertical monopole antenna.

Location	Measured Results (dB/ μ A/m)	Calculated Results (dB/ μ A/m)	Difference (dB/ μ A/m)
# 1	11.9	11.165	0.735
# 2	11.4	11.170	0.230
# 3	11.9	11.175	0.725
# 4	11.9	11.186	0.714
# 5	11.9	11.196	0.704

Table 4.5. Direct magnetic-field strength comparison for CMH transmitter. Measured results are for loop oriented for maximum response.

Location	Measured Results (dB/ μ A/m)	Calculated Results (dB/ μ A/m)	Difference (dB/ μ A/m)
# 1	-2.4	5.20	-7.60
# 2	-1.9	5.20	-7.10
# 3	-1.4	5.22	-6.62
# 4	-1.4	5.24	-6.64
# 5	-2.4	5.25	-7.65

Table 4.6. Direct magnetic-field strength comparison for DKG transmitter. Measured results are for loop oriented for maximum response.



RADIAL DISTANCE FROM RADIO TOWER IN FEET

Fig. 4.8 Calculated values of reradiated magnetic field strength and measured minimum magnetic field strength (nullled direct radiation) along the access road with respect to DKG transmitter.

4.5 Near-Zone Magnetic-Field Strength Comparison of Calculated and Measured Reradiated Fields

When the loop antenna used to measure magnetic field strength at the access road measurement points was rotated to the minimum signal position for the DKG signal, the direct signal from the NDB was approximately in the loop null. At all the five measuring locations, the alignment of the loop was simultaneously such that strong coupling existed with the currents induced on the tower.

The values of the magnetic field measured then were due primarily to the reradiated signal from the tower, other interfering signals, and noise. Unfortunately, this situation did not happen for the CMII transmitting antenna. Thus only DKG signals are compared in this section.

For near-zone reradiated magnetic-field strength calculation, a further separate computation, also based on the work of Richmond^[16] was necessary. The calculated results are shown in Fig. 4.8 and comparison with the measured values is listed in Table 4.7.

Location	Measured Results (dB/ μ A/m)	Calculated Results (dB/ μ A/m)	Difference (dB/ μ A/m)
# 1	-9.4	-19.4	10.0
# 2	-11.4	-20.3	8.9
# 3	-13.4	-21.2	7.8
# 4	-16.4	-23.1	6.7
# 5	-20.4	-24.8	4.8

Table 4.7 Near-zone reradiated magnetic-field comparison for the DKG transmitter. Measured results are for the loop oriented for minimum response.

The base of the tower is insulated from ground, and therefore the calculated values in Table 4.7 were made for this condition. The measured results are consistently higher than these calculated results indicating that more current was induced in the actual tower than predicted by the computer model. The actual tower is fed at the base through a matching device which provides a current path from the tower base to ground. However, this impedance could not be conveniently measured since the radio station broadcast 24 hours per day, nor did the station engineer have this information. However, the calculations were repeated with the tower base shorted to ground, and both open and short circuit results are shown in Fig. 4.8. The measured results for the actual tower lie nearly midway between the two calculated curves. Since the problem is linear, one would expect that if the correct tower-to-ground impedance were input to the model, the discrepancy would necessarily be less than indicated in Fig. 4.8, which is on the order of 10 dB. Also, since transmission line towers are well-grounded, this ambiguity will not exist in the intended application, and the conclusion is that the computer modeling program is valid for predicting reradiated signal levels at NDB frequencies.

4.6 Prediction of the reradiated/direct signal ratio for various powerline tower models.

At this point, we are able to investigate the levels of reradiated signals from various powerline tower models by using the computer modeling program. For this purpose, three different tower configurations are being considered. Their detailed dimensions are shown in Fig. 4.9. Each tower, in turn, is placed at 1 NM mile away from the NDB transmitter along the imaginary x-axis, which is passing through the transmitter and the powerline tower with the former being the

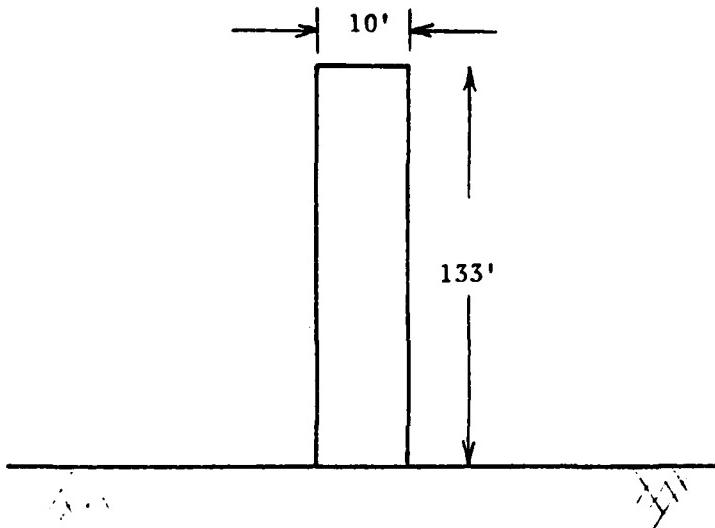


Fig. 4.9a Model of double wire steel tower

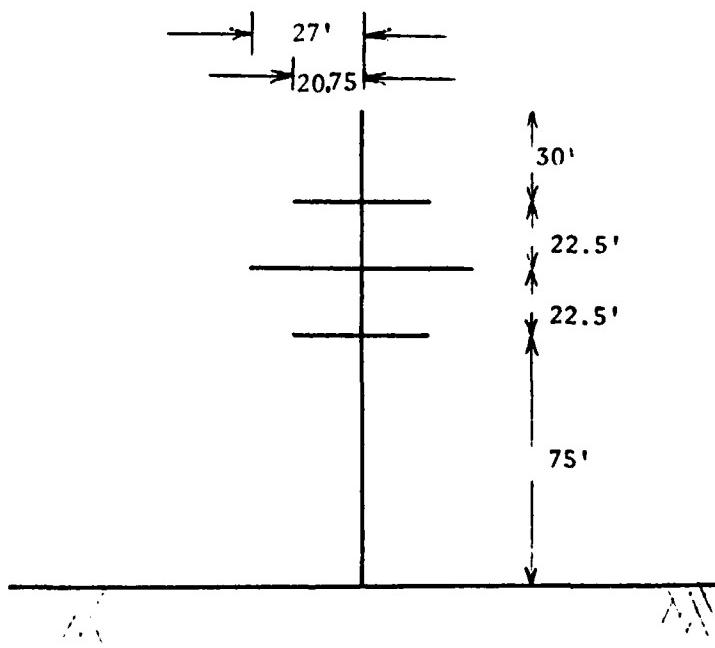


Fig. 4.9b Model of single steel tower with cross arms

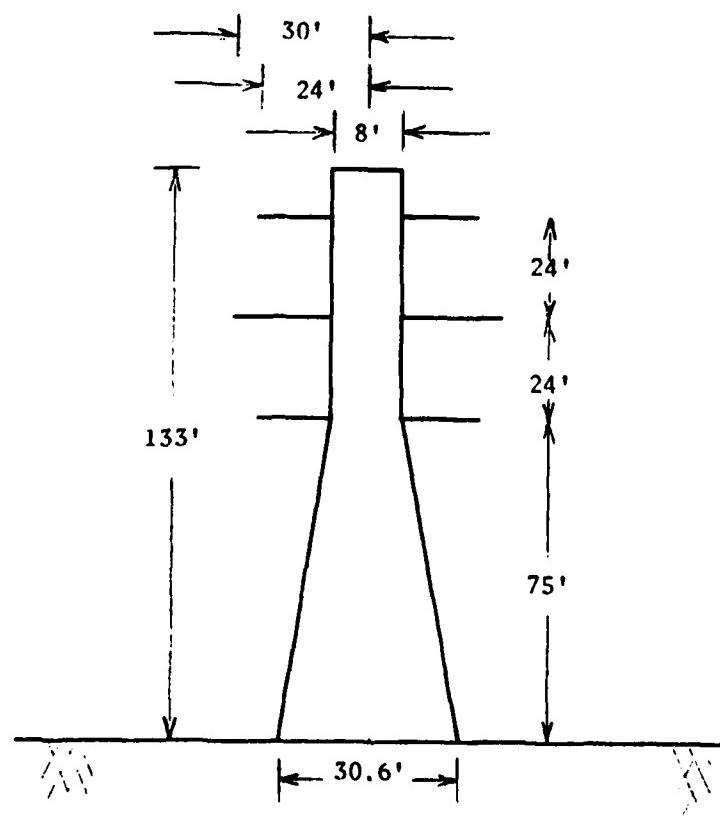


Fig. 4.9c Model of double steel tower with cross arms

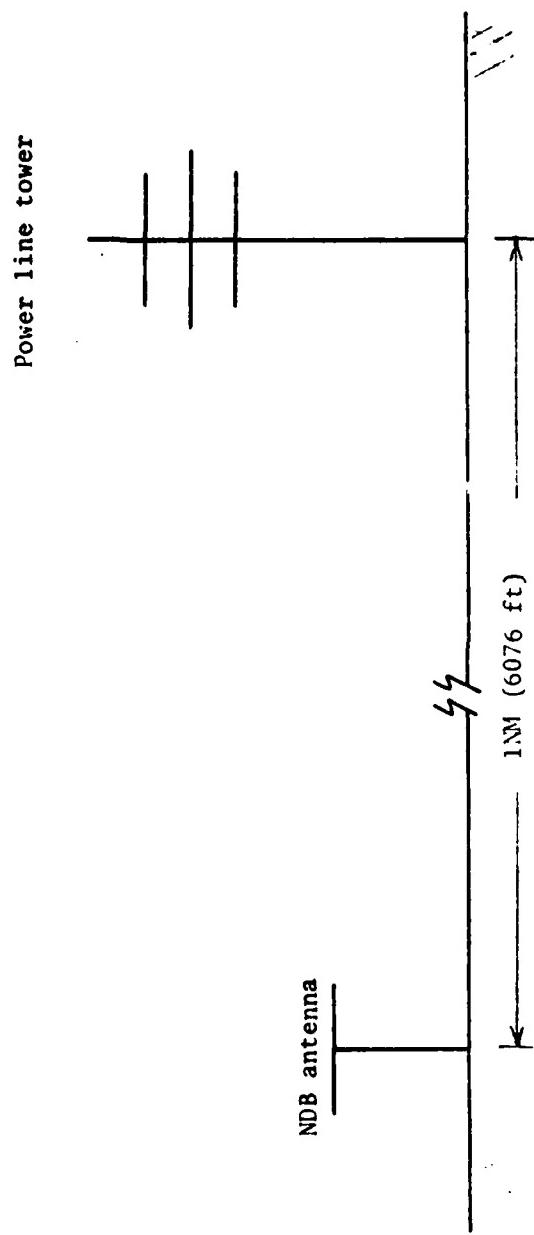


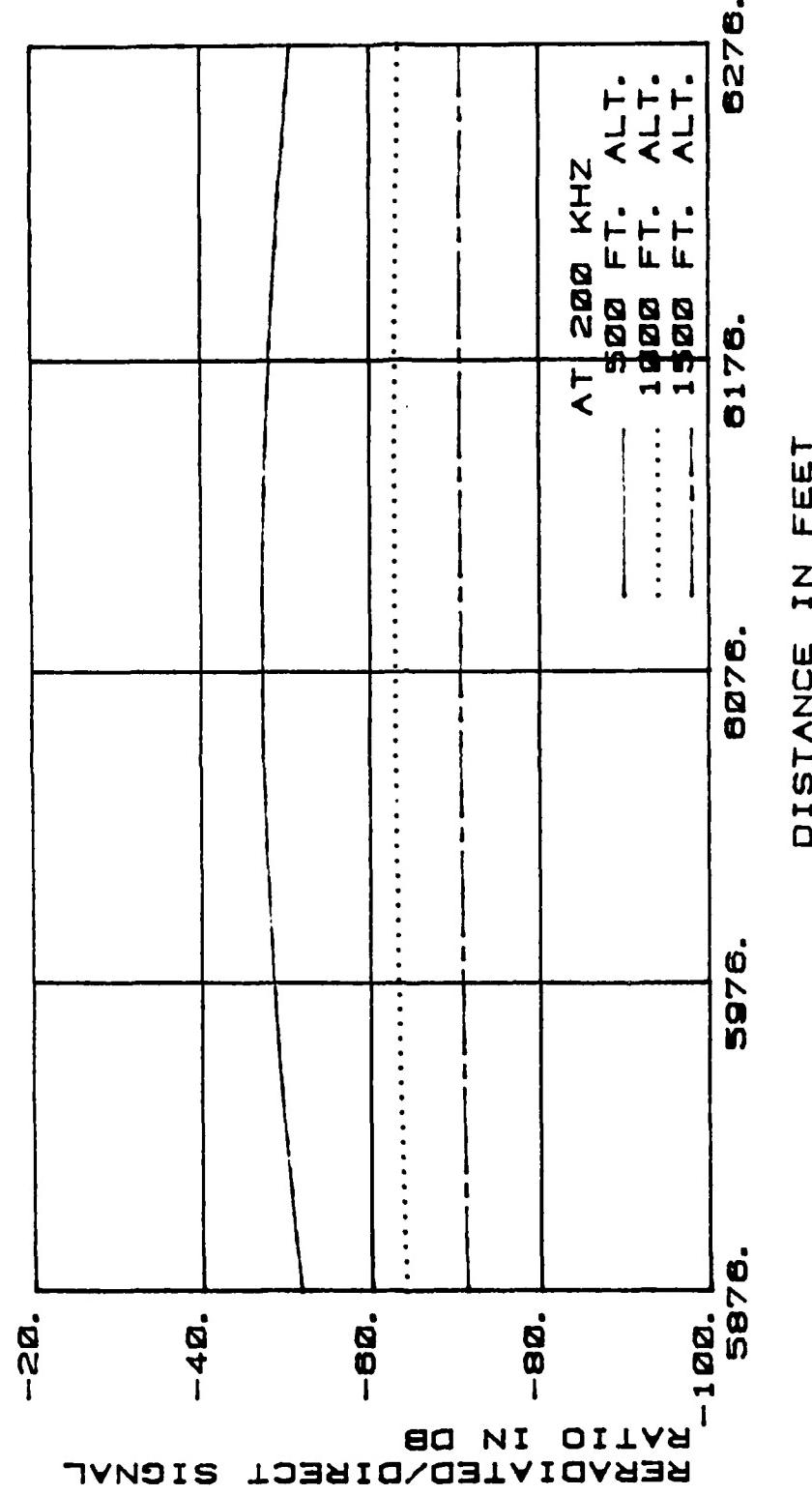
Fig. 4.10 A general layout of a powerline tower model with respect to an NDB transmitter.

origin, as illustrated in Fig. 4.10.

The reradiated/direct signal ratio is computed along the x-axis within ± 200 feet from the tower and the receiver altitudes are at 500, 1000 and 1500 feet above ground respectively. The value of ERP of the NDB transmitter is immaterial for this purpose as only the ratio of the reradiated/direct signal is being investigated. Any value of ERP of the NDB transmitter will be cancelled out in the computation for the reradiated/direct signal ratio. Similarly, the distance separating the NDB transmitter and the powerline tower does not affect the ratio greatly either. In fact, as the separating distance increases, the reradiated/direct signal ratio decreases.

The levels of the reradiated/direct signal ratio for the three different tower models at the frequencies of 200 and 500 KHz are shown in Fig. 4.11. The plots consistently show that the reradiated/direct signal ratio is much lower than the critical value of -15 dB. It appears that the different powerline tower models do not affect the reradiated/direct signal ratio a great deal, as indicated by Fig. 4.11. Based on this observation, a simplified powerline tower model, as shown in Fig. 4.12, can be conveniently used for further investigation. Fig. 4.13 confirms that the reradiated/direct signal ratio of this simplified powerline tower model is comparable to those of the three different tower models.

Using this simple tower model, a general layout as shown in Fig. 4.14, can be considered. Three tower models are placed 1000 feet apart and their alignment is perpendicular to the x-axis at 1 NM away from the NDB transmitter. The resulting reradiated/direct signal ratio is shown in Fig. 4.15. The plots indicate that the reradiated/direct



DISTANCE IN FEET

Fig. 4.11a Reradiated/direct signal ratio for double wire steel tower model at 200 kHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.

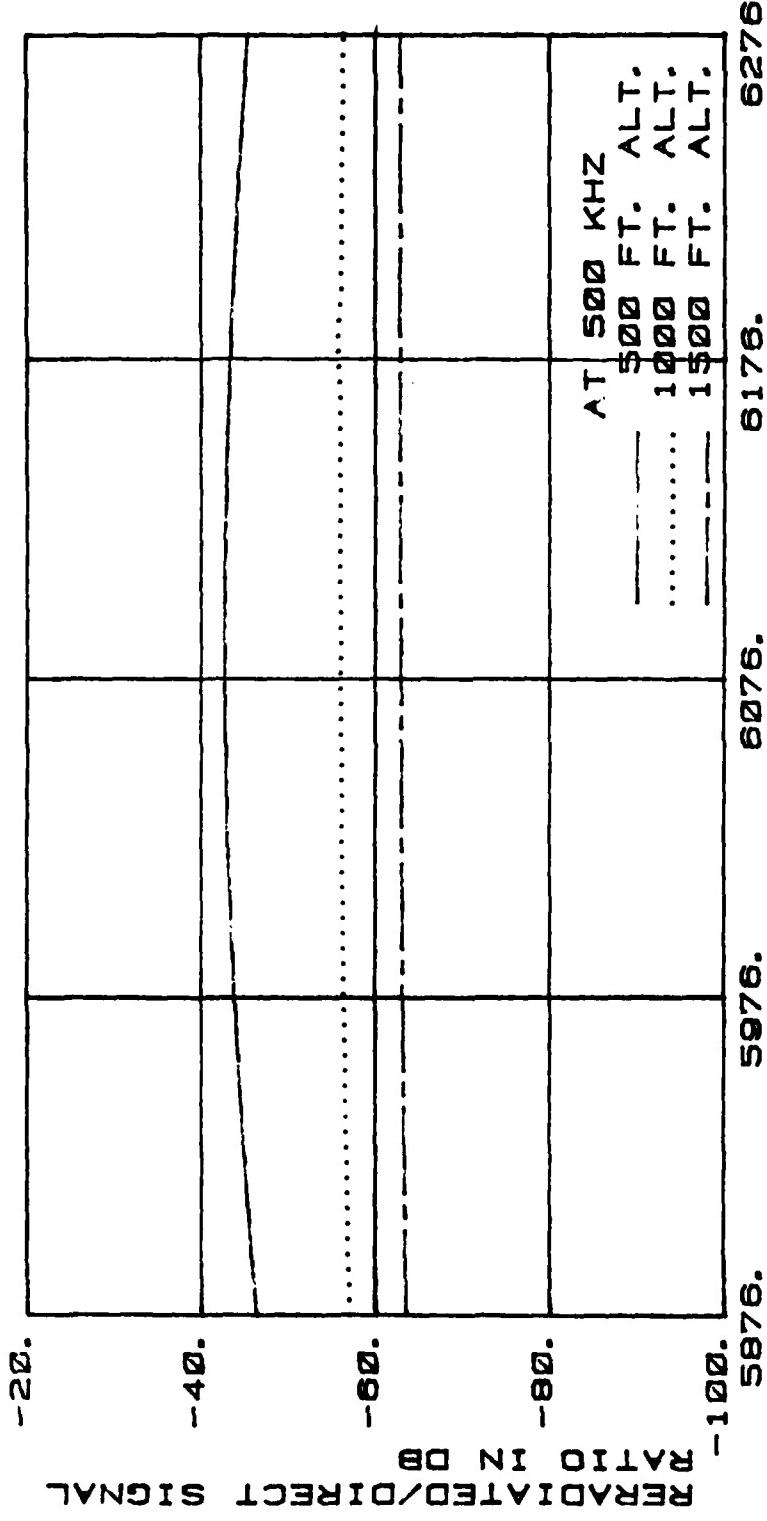
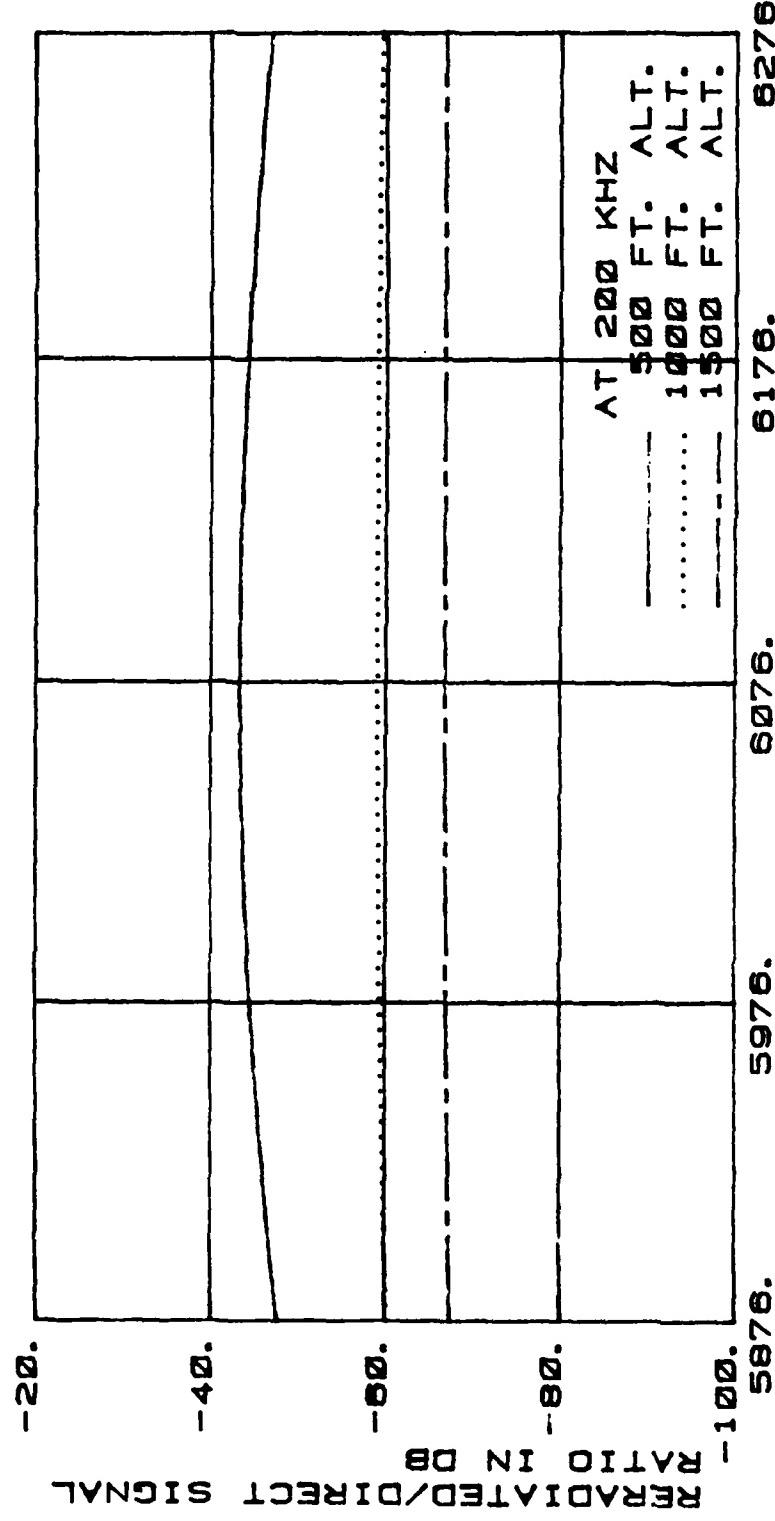
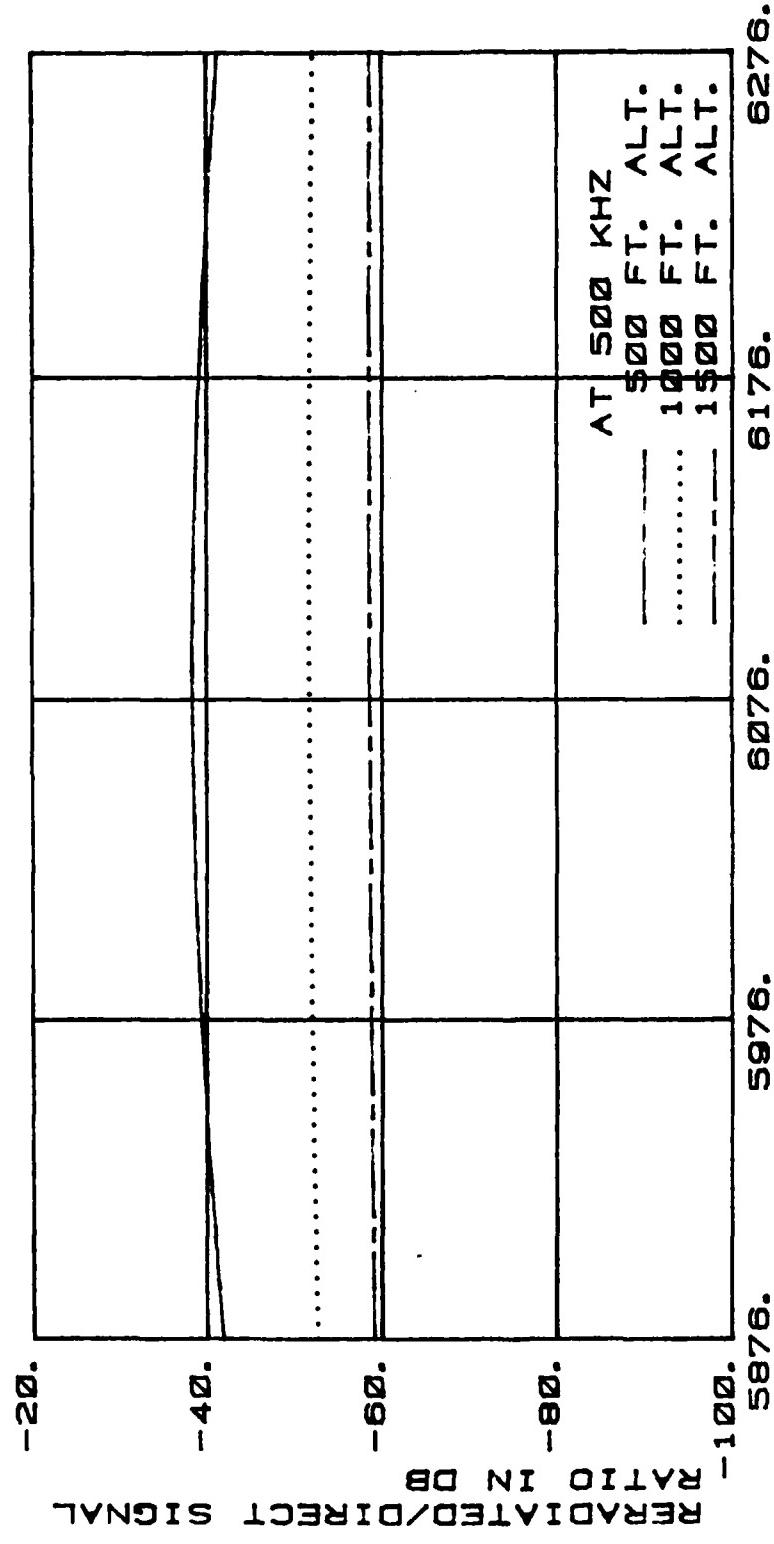


Fig. 4.11b Reradiated/direct signal ratio for double wire steel tower model at 500 kHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.



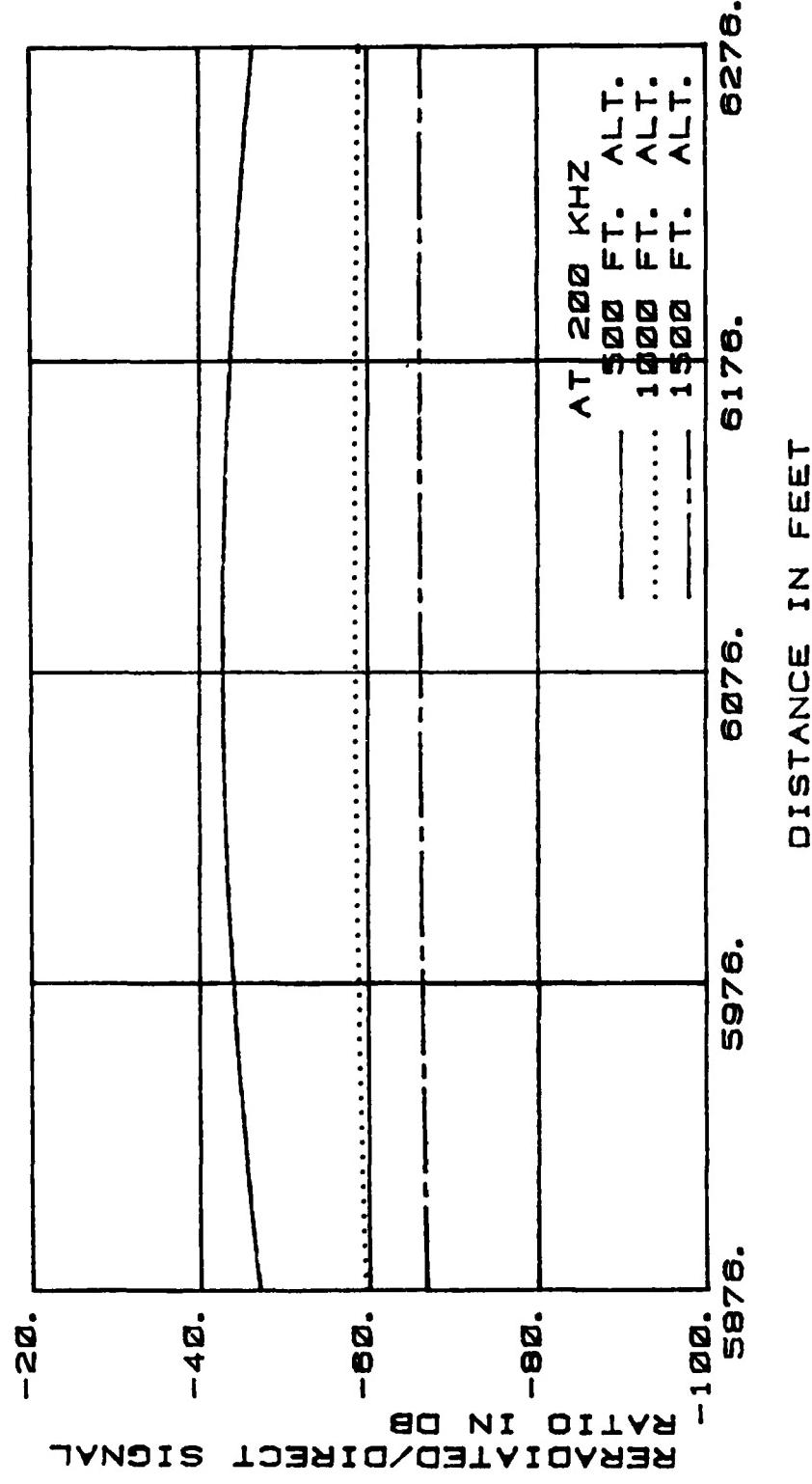
DISTANCE IN FEET

Fig. 4.11c Reradiated/direct signal ratio for single steel tower model with cross arms at 200 kHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.



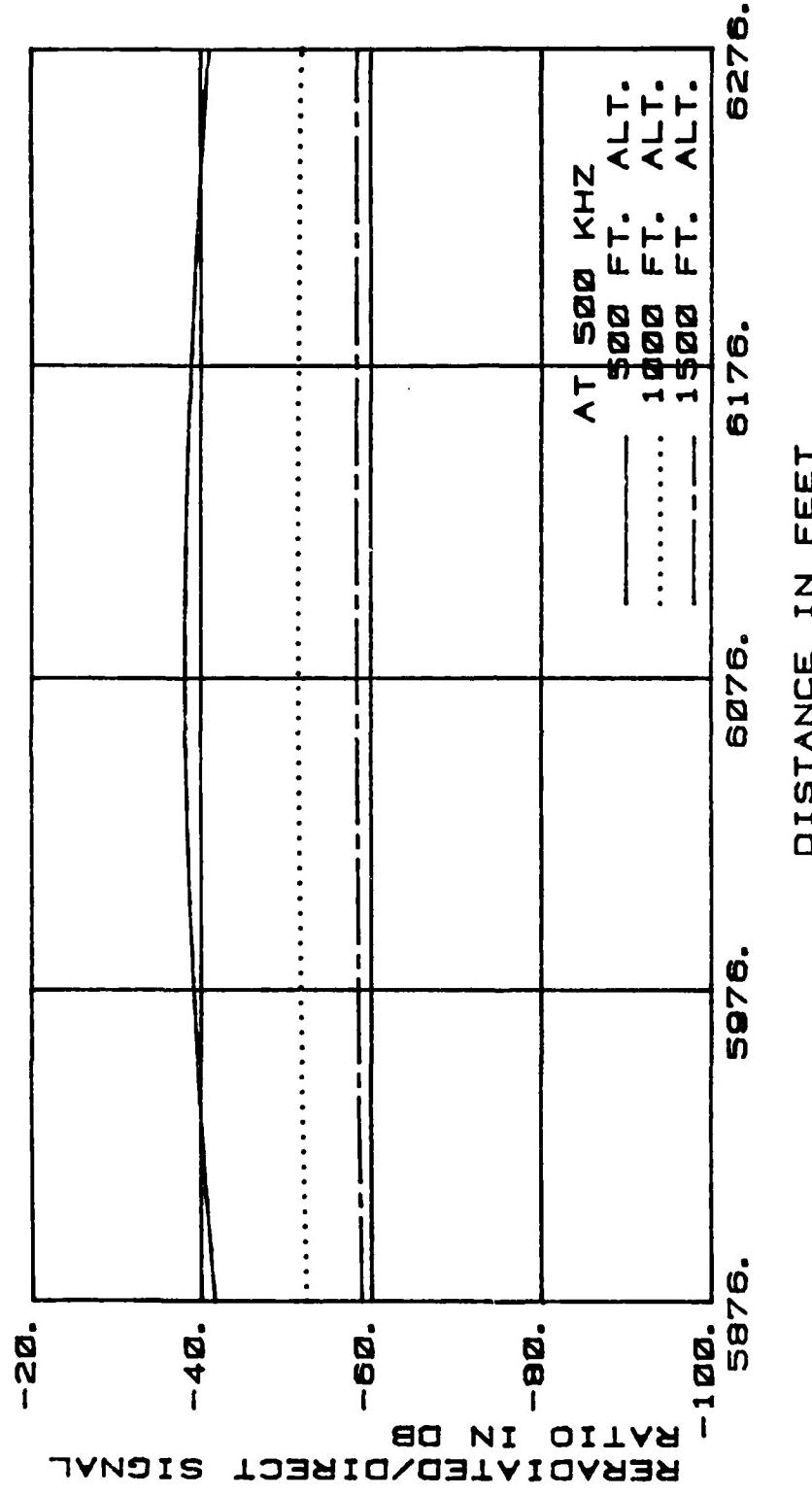
DISTANCE IN FEET

Fig. 4.11d Reradiated/direct signal ratio profile for the single steel tower model with cross arms at 500 kHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.



DISTANCE IN FEET

Fig. 4.11e Reradiated/direct signal ratio profile for double steel tower model with cross arms at 200 kHz vs distance from the NDB.
The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.



DISTANCE IN FEET

Fig. 4.11f Reradiated/direct signal ratio profile for double steel tower model with cross arms at 500 KHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.

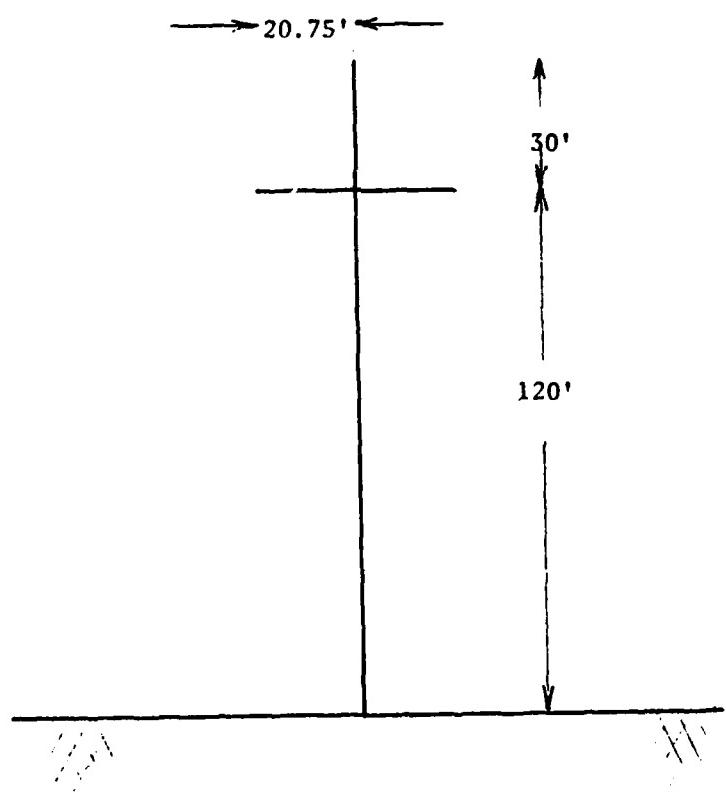


Fig. 4.12 Model of a simple powerline tower, a single steel pole with one cross arm.

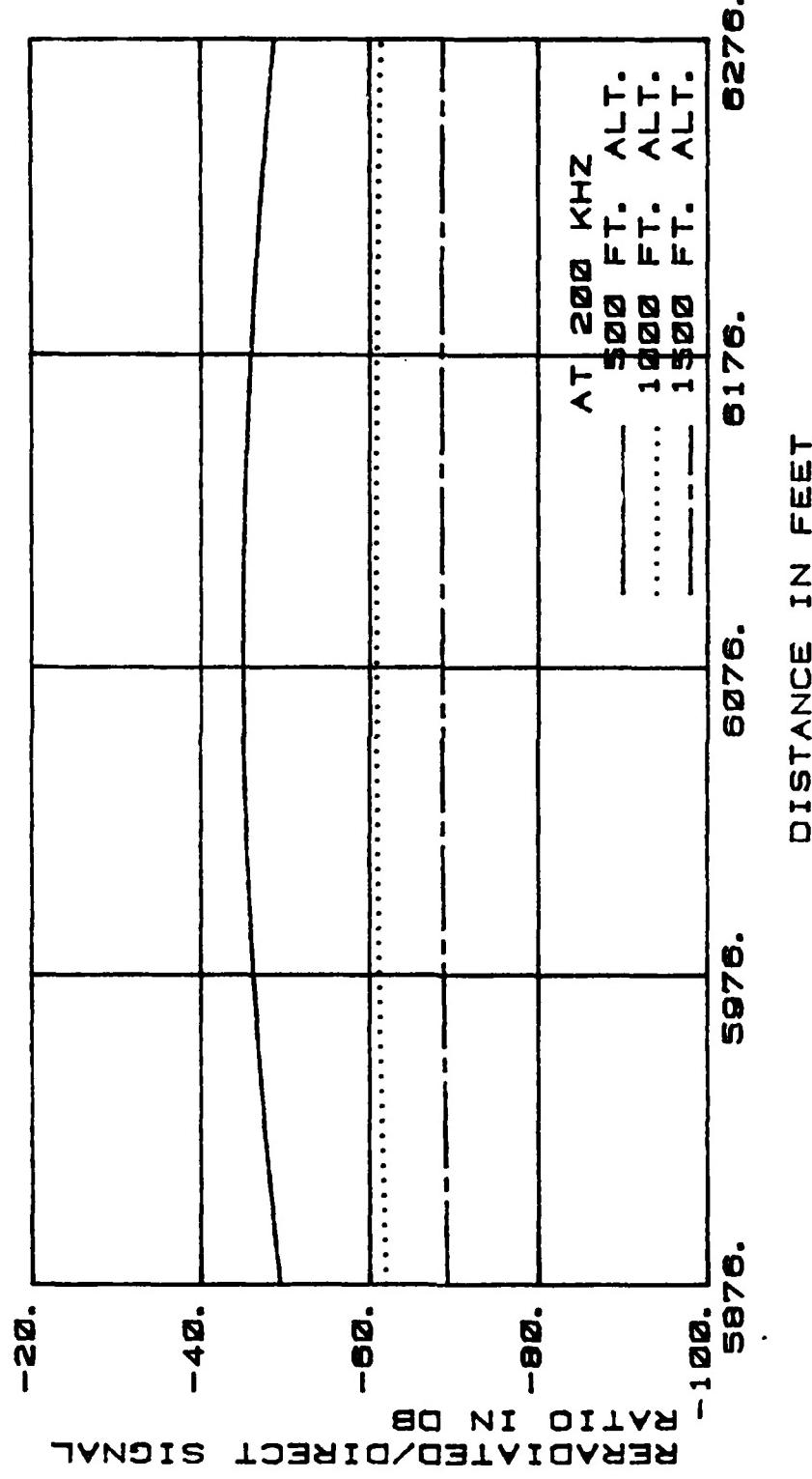


Fig. 4.13a Reradiated/direct signal ratio profile for the simple tower at 200 kHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the tower.

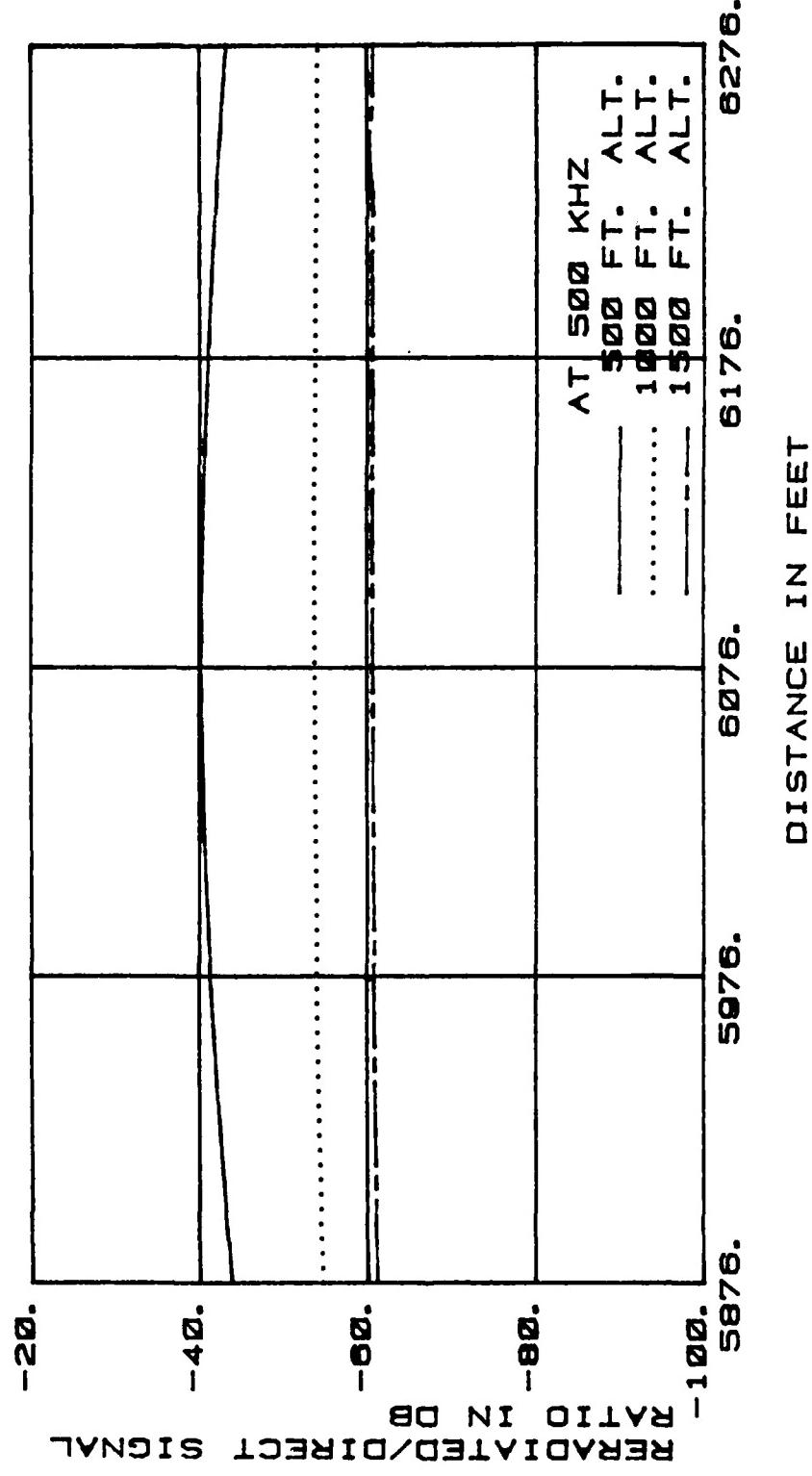


Fig. 4.13b Reradiated/direct signal ratio profile for the simple tower at 500 kHz vs distance from the NDB. The tower is at 6076 feet (1 Km) and the flight path is directly over the tower.

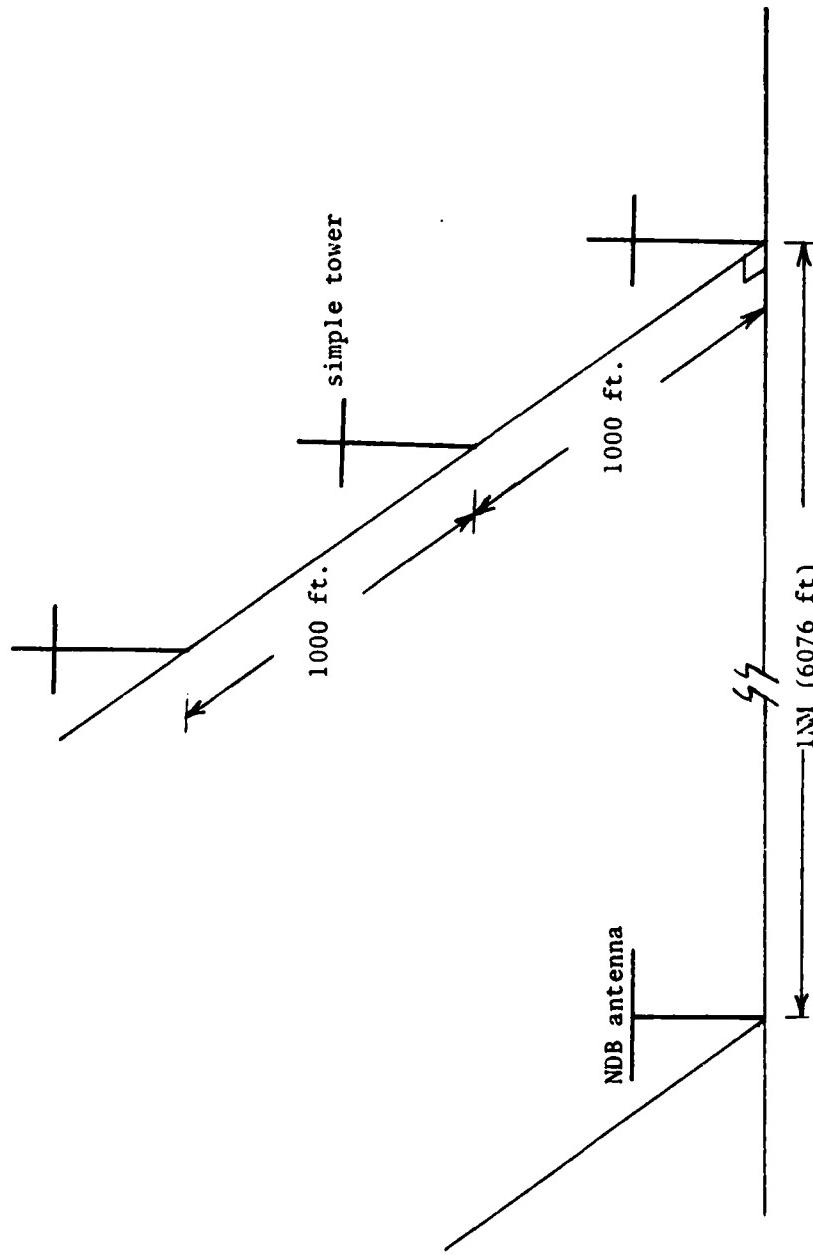


Fig. 4.14 A general layout of three simple tower models with respect to an NDB transmitter.

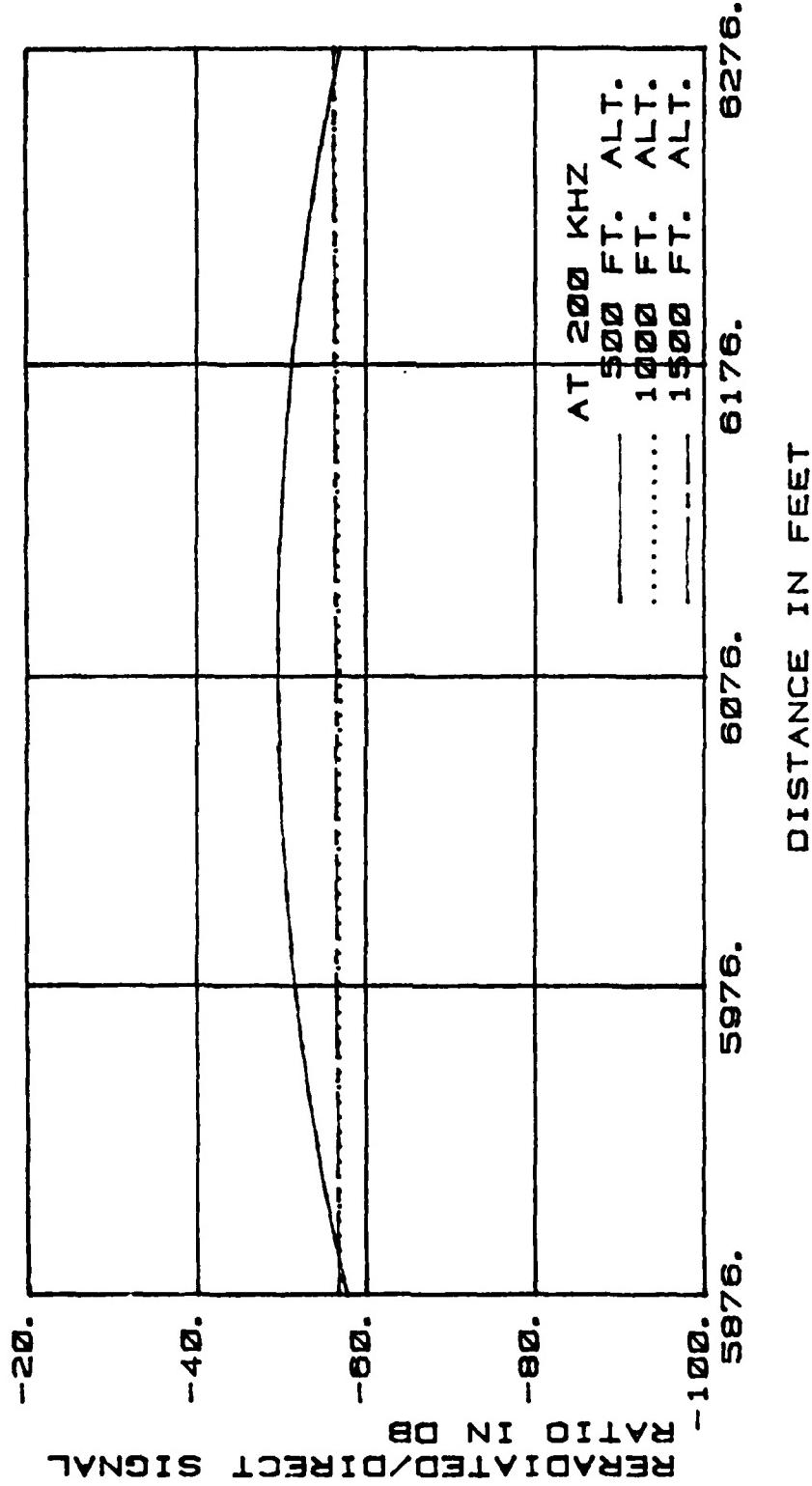


Fig. 4.15a Reradiated/direct signal ratio profile for the three tower model layout at 200 KHz vs distance from the NDB. The tower is 6076 feet (1500 ft) and the flight path is directly over closest tower.

signal ratios are well below the critical value of -15 dB.

Further, possible effects of the horizontal conductors are also investigated. The conductors are modeled as a single eight-inch diameter smooth conductor, spanning 2000 feet across the three simple towers, as shown in Fig. 4.16. The resulting reradiated/direct signal ratio is plotted in Fig. 4.17. As anticipated, the reradiated/direct signal ratios of the horizontal conductor model are much lower compared to those computed for the vertical tower models. The reason is that the vertically-polarized radiated signal from the NDB transmitter reacts minimally with the horizontal conductors.

4.7 Conclusion

The results of Section 4.6 have consistently shown that the reradiated/direct signal ratio is well below the critical value of -15 dB even for flight paths only 500 feet above ground. Thus, it can be concluded that the reradiated signals from powerline structures, line conductors included, should not interfere with normal ADF operation.

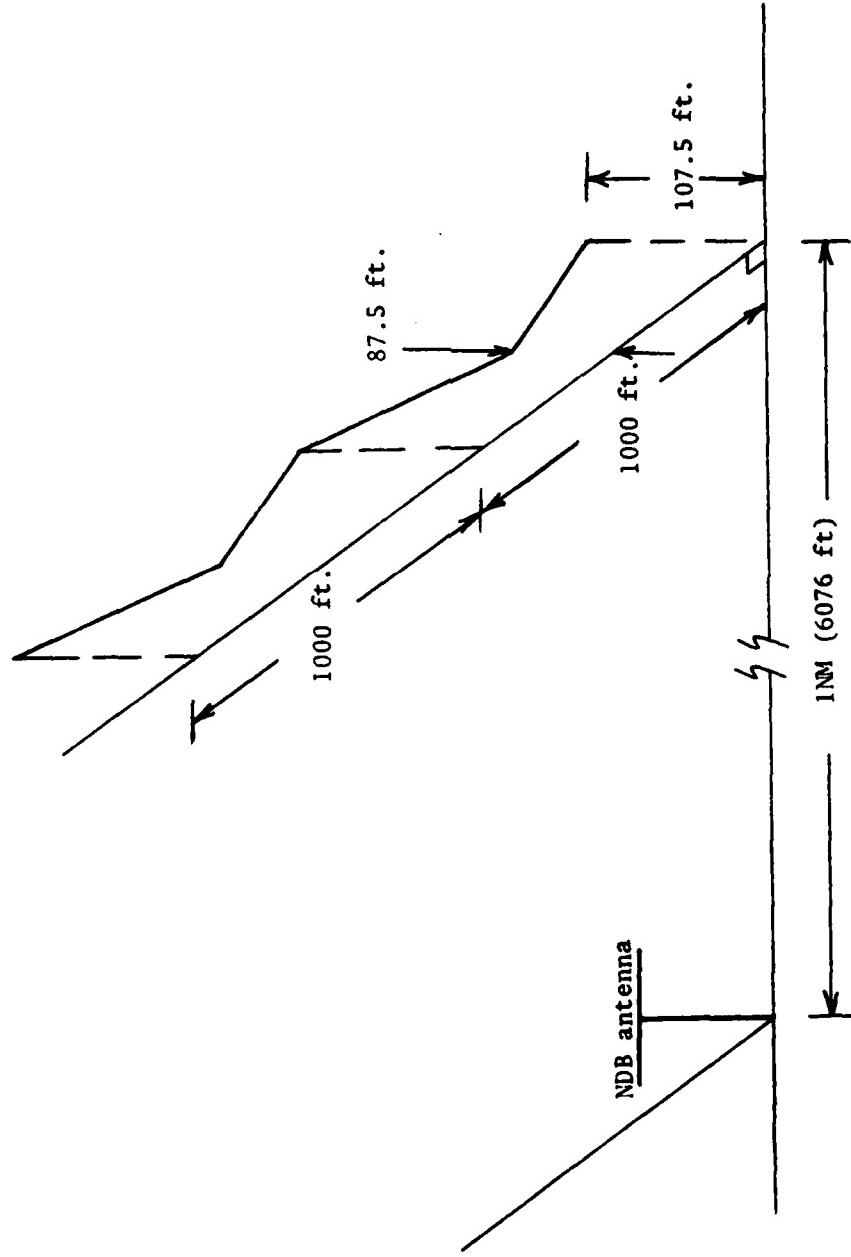


Fig. 4.16 Model of horizontal line conductor spanning across the three towers with respect to an NDB transmitter.

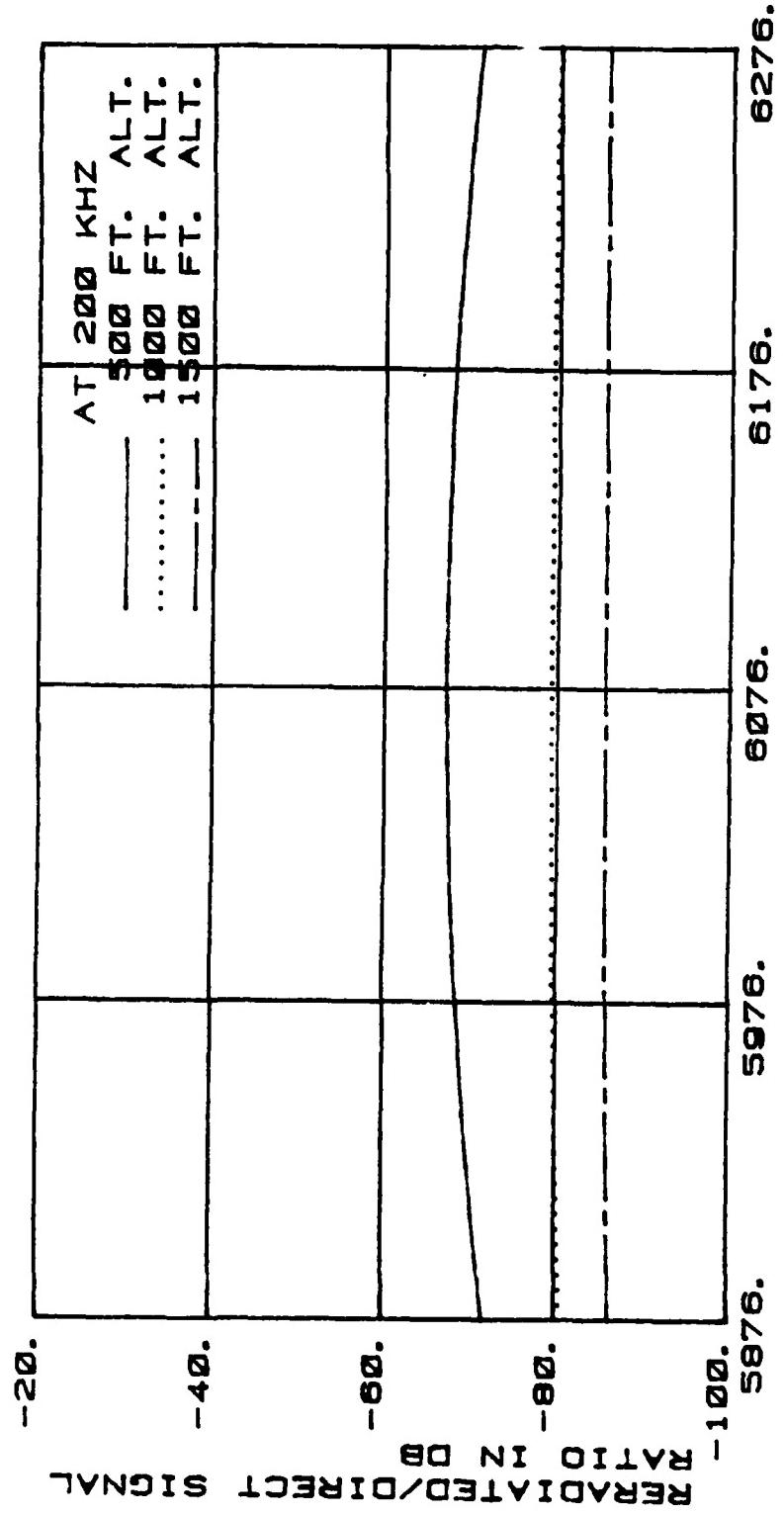


Fig. 4.17a Reradiated/direct signal ratio profile for the horizontal line conductor model at 200 kHz vs distance from the NDB. The tower is at 6076 feet (1 NM) and the flight path is directly over the closest tower.

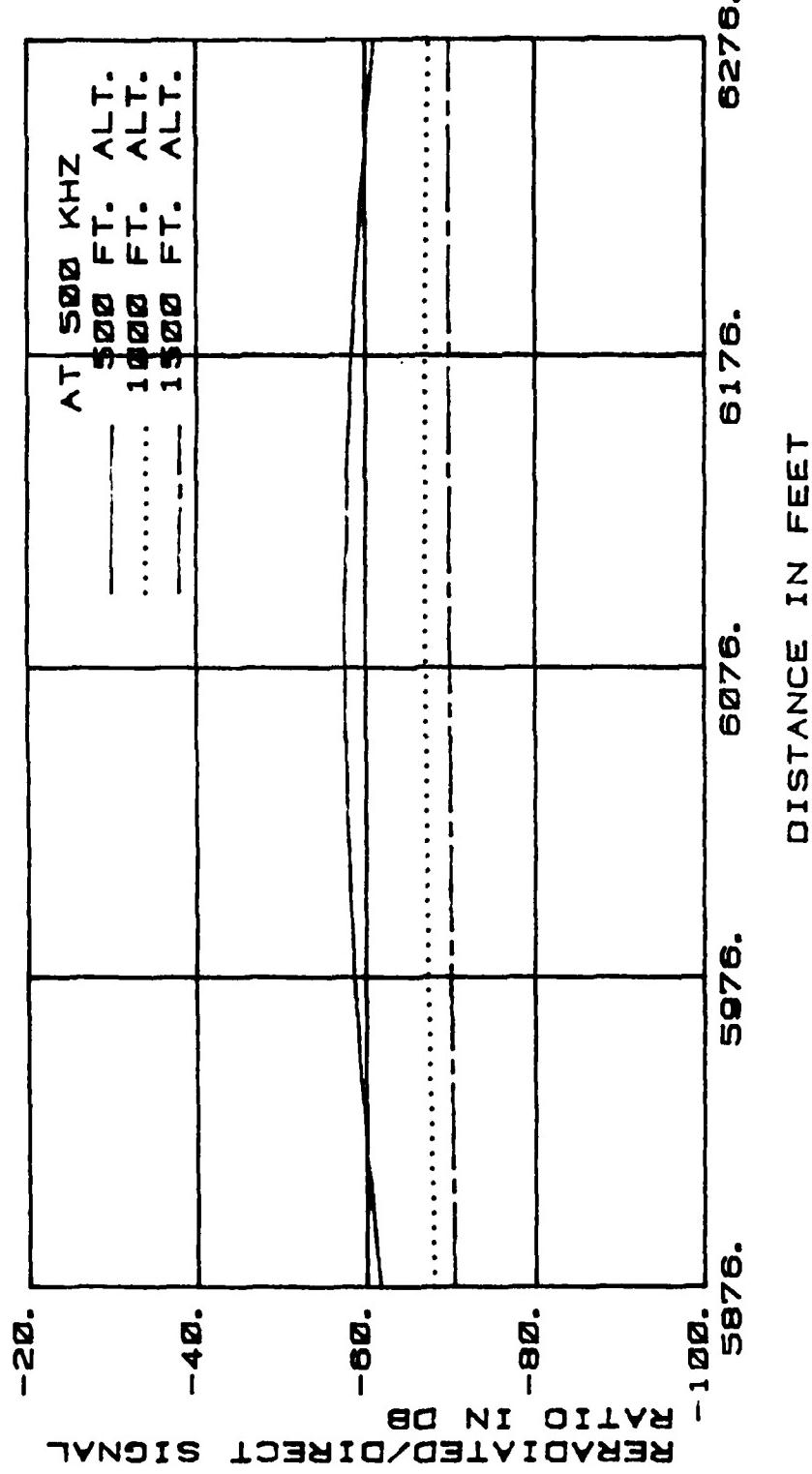


Fig. 4.17b Reradiated/direct signal ratio profile for the horizontal line conductor model at 500 kHz vs distance from the NDB. The tower is 6076 feet (1 N) and the flight path is directly over the closest tower.

CONCLUSIONS

The objective of this report is to assess the possibilities of harmful interference with ADF operation being caused by electric power transmission lines. The two modes of interference considered are corona radio noise generated actively by the transmission lines, and passive reradiation of the radio signal from the NDB by the transmission line structures.

In order to achieve this objective, computer programs were developed which can predict the critical distance between the aircraft containing the ADF receiver and the power transmission line where the ratio of desired signal to either transmission line noise or reradiated signal is 15 dB. These predictions can be made as a function of the distance separating the NDB transmitter and the powerline, the elevation of the flying aircraft (and hence the ADF receiver), the ERP of the NDB transmitter, the geometry and voltage of the powerline, and the frequency. For the case of generated radio noise, the permittivity and conductivity of the earth can also be varied; however, for the passive reradiation case the earth is assumed to be perfectly conducting.

Regarding active generation of radio noise, AC lines generate considerably more radio noise than do DC lines. However, even for the worst case considered in this study, a 765 kV AC powerline located 20 nautical miles from a 200 kHz NDB, the results show that for an aircraft flying at only a 500 feet altitude, the aircraft if on a path through NDB location and perpendicular to the powerline, would have to approach to less than 4000 feet from the powerline before the ADF signal to noise ratio dropped below 15 dB. The result is for a weather

condition of heavy rain, which causes an AC line to generate the highest level of radio noise. If the NDB is located more closely to the power-line, the radio noise has relatively less effect on ADF performance since the desired NDB signal level is increased while the radio noise level remains unchanged.

Moving the NDB closer to the power transmission structures does, however, increase the likelihood of ADF interference due to passive reradiation of the NDB signal by the powerline structures. The possibility of such interference was estimated using a computer simulation model based on the method of moments. However, even for the worst case considered which had a 500 kHz NDB located one nautical mile from a single steel tower with the aircraft flying over the tower at an altitude of 500 feet, the reradiated signal was calculated to be approximately 38 dB below the level of the directly radiated (desired) signal. The fundamental reason for this is that the wavelength of the NDB signals, even at 500 kHz, is large compared to the tower dimensions.

Thus the conclusion is that locating an NDB near a high voltage transmission line (up to within 1 nautical mile) would probably not impair the function of the NDB due to either corona noise generation or passive reradiation from the line. However, as shown by the worst-case results previously mentioned, there is a possibility of interference for a situation which involves a low power beacon located at a relatively large distance from a potentially interfering power line. And, it should be pointed out that other possible interference mechanisms, such as power-line carrier radiation, have not been considered in this study.

REFERENCES

- [1] Frequency Management Engineering Principles I/M Frequency Assignment Criteria, An FAA Handbook (#6050.10 11/23/65)
- [2] W.E. Pakala, V.L. Chartier, "Radio Noise Measurement on Overhead Power Lines from 2.4 to 800 kV", IEEE Transaction on Power Apparatus and Systems, Vol. PAS-90, No. 3 May/June 1971, pp. 1155-1165.
- [3] IEEE Committee Report, "Review of Technical Considerations on Limits to Interference from Power Lines and Stations", IEEE Transaction on Power Apparatus and System, Vol. PAS-99, No. 1, Jan/Feb 1980, pp.365-388.
- [4] IEEE Committee Report, "Comparison of Radio Noise Prediction Methods with CIGRE/IEEE Survey Results", IEEE Transaction on Power Apparatus and System, Vol. PAS-92, No.3, May/June 1973, pp. 1029-1042.
- [5] IEEE/PAS Special Course, A Short course presented by the corona and field effect subcommittee of transmission distribution committee, September 24-28, 1979 at South Bend, Indiana, Ch. 4.2.
- [6] IEEE Committee Report, "A Survey of Methods for Calculating Transmission Line Conductor Surface Voltage Gradients", IEEE Transaction on Power Apparatus and System, Vol. PAS-98, No.6 Nov/Dec 1979, pp. 1996-2007.
- [7] M.R. Moreau, C.H. Gary, "Predetermination of the Radio Interference Level of High Voltage Transmission Lines. I-Predetermination of the Excitation Function", IEEE Transaction on Power Apparatus and System, Vol. PAS-91, Jan/Feb. 1972, No. 1, pp. 284-291.
- [8] Transmission Line Reference Book 345 kV and above, Electric Power Research Institute, Palo Alto, 1975.
- [9] Wait, J.R., "Electromagnetic Surface Waves", Advances in Radio Research, Edited by J.A. Saxtor, Vol. 1, pp. 157-217, Academic Press, London, 1964.
- [10] Harrington, R.F., "Time-Harmonic Electromagnetic Fields", pp. 77-81, McGraw-Hill Book Company, 1961.
- [11] Abramowitz, M. and I.A. Stegun, Handbook of Mathematical Functions, National Bureau of Standards, AMS 55, U.S. Government Printing Office, Washington, D.C., 1964.

- [12] Transmission Line Reference Book HVDC to ± 600 kV, Electric Power Research Institute, Palo Alto, 1977.
- [13] E.H. Gehrig, A.C. Peterson, C.F. Clark and T.C. Rednour, "Bonneville Power Administration's 1100 kV Direct Current Test Project: II- Radio Interference and Corona Loss", IEEE Transaction on Power Apparatus and System, Vol. PAS-86, No. 3, March 1967, pp. 278-290.
- [14] G.L. Reiner, E.H. Gehrig, "Celilo-Sylmar 400 kV Line RI Correlation with Short Test Line", IEEE Transaction on Power Apparatus and System, Vol. PAS-96, No. 3, May/June 1977, pp. 955-961.
- [15] Richmond, J.H., "Radiation and Scattering by Thin-Wire Structures in a Homogeneous Conducting Medium", IEEE Transaction on Antenna and Propagation, March 1974.
- [16] Richmond, J.H., "Radiation and Scattering by Thin Wire Structures in the Complex Frequency Domain", Technical Report 2902-10, July 1973, pp.36-37.

APPENDICES

APPENDIX A

Derivation for equation of field factor
for point P anywhere in space

Assuming a quasi-static condition, the magnetic fields can be viewed as being produced only from the current through the line conductor.

Application of Ampere's law to the current carrying conductor gives the magnetic fields in space around the conductor. This is illustrated in Fig. A-1 below for the magnetic fields at ground level due to corona generated currents in the line conductor.

Using

$$H = \frac{I}{2\pi r} \quad (\text{A-1})$$

then, from Fig. A-1,

$$H_L = H_i = \frac{I}{2\pi} \cdot \frac{1}{\sqrt{x^2 + h^2}} \quad (\text{A-2})$$

The resultant magnetic field H_R is given by

$$H_R = 2H_L \cdot \cos \theta \quad (\text{A-3})$$

$$= 2 \cdot \frac{I}{2\pi} \cdot \frac{h}{x^2 + h^2} \quad (\text{A-4})$$

Thus,

$$H_R = \frac{I}{2\pi} \cdot \frac{2h}{x^2 + h^2} \quad (\text{A-5})$$

in magnitude and in the horizontal direction as shown.

Assuming a TEM mode of wave propagation, the corresponding electric field can be obtained by the equation

$$E = Z_0 H \quad (\text{A-6})$$

where Z_0 is the intrinsic impedance of free space and $Z_0 = 120\pi$.

Therefore,

$$E = 120\pi \cdot H_R \quad (\text{A-7})$$

$$= 120 \cdot \frac{I}{2\pi} \cdot \frac{2h}{x^2 + h^2} \quad (\text{A-8})$$

$$= 60 \cdot I \cdot \frac{2h}{x^2 + h^2} \quad (\text{A-9})$$

The direction of the electric field is vertical, perpendicular to the magnetic field as shown in Fig. A-1.

Normally, when dealing with magnetic field, it is adequate to consider the line conductor in free space without any image. However, if the earth is assumed perfectly conducting, the image will act to double the field at ground level due to symmetry. In all the sections dealing with powerline conductors in this report, it is assumed that the earth is perfectly conducting and thus fields due to image conductors are also being considered.

For any point in space, as shown in Fig. A-2, the magnetic field due to corona generated currents in the powerline conductor can be determined.

The horizontal component of the magnetic field is given by

$$H_x = H_i \cos \beta - H_\ell \cos \alpha \quad (\text{A-10})$$

$$= \frac{I}{2\pi r_i} \cdot \left(\frac{(h_p + h)}{r_i} \right) - \frac{I}{2\pi r_\ell} \cdot \left(\frac{(h_p - h)}{r_\ell} \right) \quad (\text{A-11})$$

$$= \frac{I}{2\pi} \cdot \left(\frac{h_p + h}{r_i^2} - \frac{h_p - h}{r_\ell^2} \right) \quad (\text{A-12})$$

$$= \frac{I}{2\pi} \cdot \left[\frac{h_p + h}{x^2 + (h_p + h)^2} - \frac{h_p - h}{x^2 + (h_p - h)^2} \right] \quad (\text{A-13})$$

Similarly, the vertical component of the magnetic field is given by

$$H_z = H_\ell \sin \alpha - H_i \sin \beta \quad (\text{A-14})$$

$$= \frac{I}{2\pi r_\ell} \cdot \frac{x}{r_\ell} - \frac{I}{2\pi r_i} \cdot \frac{x}{r_i} \quad (\text{A-15})$$

$$= \frac{Ix}{2\pi} \cdot \frac{1}{r_\ell^2} - \frac{Ix}{2\pi} \cdot \frac{1}{r_i^2} \quad (\text{A-16})$$

$$= \frac{I}{2\pi} \cdot \left(\frac{1}{x^2 + (h_p - h)^2} - \frac{1}{x^2 + (h_p + h)^2} \right) \quad (\text{A-17})$$

thus, the resultant magnetic field is given by

$$H_R = \sqrt{H_x^2 + H_z^2} \quad (\text{A-18})$$

whose direction is as shown in Fig. A-2.

The corresponding electric field is then

$$E = 120\pi \cdot H_R \quad (\text{A-19})$$

$$= 120\pi \cdot \sqrt{H_x^2 + H_z^2} \quad (\text{A-20})$$

$$= 120\pi \cdot \left\{ \left(\frac{I}{2\pi} \right)^2 \cdot \left[\frac{\frac{h_p + h}{p}}{x^2 + (h_p + h)^2} - \frac{\frac{h_p - h}{p}}{x^2 + (h_p - h)^2} \right]^2 \right\}$$

$$\left(\frac{Ix}{2\pi} \right)^2 \cdot \left[\frac{1}{x^2 + (h_p - h)^2} - \frac{1}{x^2 + (h_p + h)^2} \right]^2 \}^{1/2} \quad (\text{A-21})$$

Simplifying equation (A-21) yields

$$E = 60 \cdot I \cdot \left\{ \left[\frac{\frac{h_p + h}{p}}{x^2 + (h_p + h)^2} - \frac{\frac{h_p - h}{p}}{x^2 + (h_p - h)^2} \right]^2 + \kappa^2 \left[\frac{1}{x^2 + (h_p - h)^2} - \frac{1}{x^2 + (h_p + h)^2} \right]^2 \right\}^{1/2} \quad (\text{A-22})$$

The direction of the electric field is perpendicular to the magnetic field as shown in Fig. A-2. Equation (A-22) can be written as

$$E = I \cdot F \quad (\text{A-23})$$

where F is termed the field factor.

In applying modal analysis for the computation of the RI noise radiated from the 3-phase AC powerlines, the resultant RI noise for each phase is related to the modes by the equation

$$E_{\text{phase}=n} = \sqrt{E_{m=1}^2 + E_{m=2}^2 + E_{m=3}^2} \quad (\Lambda-24)$$

where m denotes the mode number and $n = 1, 2$ or 3 . This operation is detailed in section 2.2.

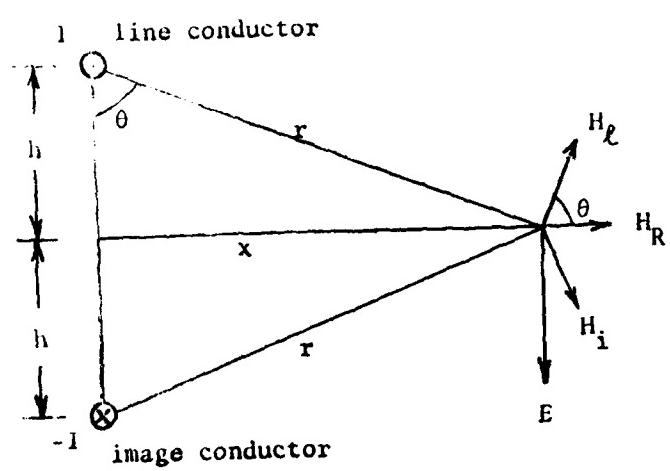


Fig. A-1. Illustration of the magnetic and electric fields at ground level due to current I in a line conductor above a perfectly conducting ground.

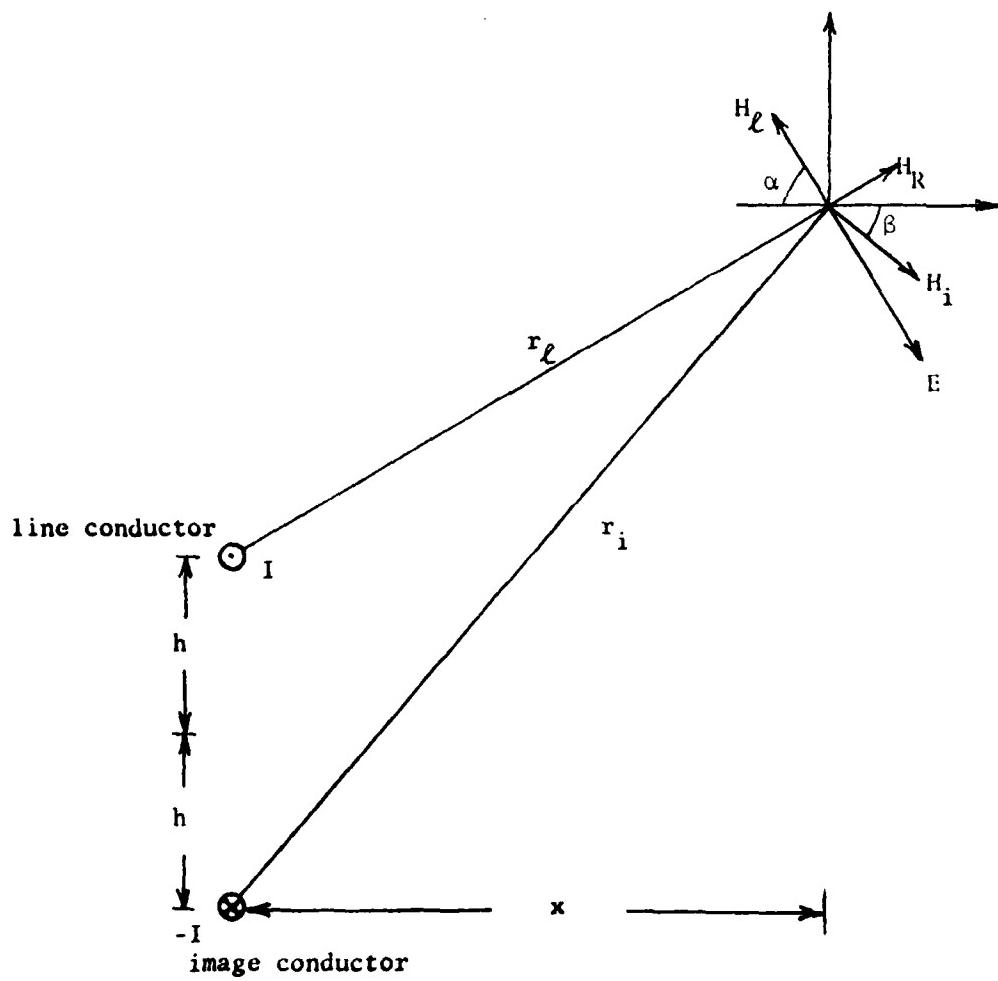


Fig. A-2. Illustration of the magnetic and electric fields at any point in space due to current I in a line conductor above a perfectly conducting ground.

APPENDIX B

Program CHARGE listing for computing the values
of the total charge on each conductor bundle

FILE # 14814 FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

FILE: CHARGE FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

```

      VAR = X*ALOG((YLOC(1))-YIMAGE(1))/GMR(1)           SAT00560
      PMAT(1,1) = VAR                                     SAT00570
      TRMAT(1,1) = CMPLX(VAR,0.)                         SAT00580
      NOKY = NCOND-1                                     SAT00590
      DO 10 I = 1,NOKY                                 SAT00600
      L = I+1                                         SAT00610
      DO 10 J = L,NOKY                                 SAT00620
      DIST1=SORT((YLOC(1)-YLOC(J))**2+(XLOC(1)-XLOC(J))**2) SAT00630
      DIST2=SORT((YLOC(1)-YIMAGE(J))**2+(XLOC(1)-XLOC(J))**2) SAT00640
      VAR = X*ALOG(DIST2/DIST1)                         SAT00650
      TRMAT(I,J) = CMPLX(VAR,0.)                         SAT00660
      PMAT(I,J) = VAR                                   SAT00670
      PMAT(J,I) = VAR                                   SAT00680
      10   TRMAT(J,I)= TRMAT(I,J)                      SAT00690
      RETURN                                              SAT00700
      END                                                 SAT00710
      SUBROUTINE CRUNCH                                SAT00720
      COMMON /CDRNS/ XLOC(100),YLOC(100),YIMAGE(100),GMR(100) SAT00730
      COMMON /INTGRS/ IRO,IMP,NCOND,NPSP,ISNFLG,J2,IPIVOT SAT00740
      COMMON /COMPLX/ TRMAT(100,101),V(100)             SAT00750
      COMMON /CONSTS/ CONST,TPIK,ZERO,XMIN,XINC          SAT00760
      COMMON /REALS / PMAT(100,100)                      SAT00770
      COMMON /TRM/ TRMAT,V,FFIELD,CONST                 SAT00780
      J2 = NCOND+1                                      SAT00790
      C
      C      FETCH V+S
      C
      DO 555 I = 1,NCOND                           SAT00800
      555  TRMAT(I,J2) = V(I)                         SAT00810
      C      REGIN GAUSS-JORDAN ELIMINATON
      DO 101 IPIVOT= 1,NCOND                         SAT00820
      IF ((ABS(TRMAT(IPIVOT,IPIVOT))) .LE. ZERO) CALL SWAPR SAT00830
      IF ((ISNFLG) .EQ. 98,99,98                      SAT00840
      99    DO 102 IROW = 1,NCOND                     SAT00850
      IF ((IROW .EQ. IPIVOT)) GO TO 102            SAT00860
      IF ((ABS(TRMAT(IROW,IPIVOT))/TRMAT(IPIVOT,IPIVOT)) .LE. ZERO) SAT00870
      >     GO TO 102
      CONST = -(TRMAT(IROW,IPIVOT)/TRMAT(IPIVOT,IPIVOT)) SAT00880
      DO 102 ICOL = 1,J2                            SAT00890
      102  TRMAT(IROW,ICOL)=TRMAT(IROW,ICOL)+CONST*TRMAT(IPIVOT,ICOL) SAT00900
      101  CONTINUE
      DO 105 IROW = 1,NCOND                         SAT00910
      IF (IROW .NE. IPIVOT) TRMAT(IROW,IROW)           SAT00920
      TRMAT(IROW,J2)= TRMAT(IROW,J2)/CONST           SAT00930
      105  CONTINUE
      RETURN                                            SAT00940
      98  WRITE(6,255)
      255  FORMAT(1H1,'TRANSMISSION MATRIX IS SINGULAR, EXECUTION',
      >           'TERMINATING')
      CALL EXIT
      END

```

FILE: CHARGE FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LABO

```

C SUBROUTINE SWAPRW
COMMON /COORDS/ XLOC(100),YLOC(100),YIMAGE(100),GMR(100)
COMMON /INTGRS/ IRD,IWR,NCOND,NPSPP,ISNFLG,J2,IPIVOT
COMMON /COMPLX/ TRMAT(100,101),V(100)
COMMON /CONSTS/ CONST,TPIK,ZERO,XMIN,XINC
COMMON /REALS / PMAT(100,100)
COMPLEX TRMAT,V,EFIELD,CONST
SAT01110
SAT01120
SAT01130
SAT01140
SAT01150
SAT01160
SAT01170
SAT01180
SAT01190
SAT01200
SAT01210
SAT01220
SAT01230
SAT01240
SAT01250
SAT01260
SAT01270
SAT01280
SAT01290
SAT01300
SAT01310
SAT01320
SAT01330
SAT01340
SAT01350
SAT01360
SAT01370
SAT01380
SAT01390
SAT01400
SAT01410
SAT01420
SAT01430
SAT01440
SAT01450
SAT01460
SAT01470
SAT01480
SAT01490
SAT01500
SAT01510

C VARIABLE *FIXIT* IS USED ONLY IN SUBROUTINE SWAPRW.
C
C COMPLEX FIXIT
IF (IPIVOT.EQ.NCOND) GO TO 1
IRWSH = IPIVOT + 1
IF ((ICARS(TRMAT(IRWSH,IPIVOT))).LE.ZERO) GO TO 2
DO 4 ICOLSH = 1,J2
  FIXIT = TRMAT(IPIVOT,ICOLSH)
  TRMAT(IPIVOT,ICOLSH) = TRMAT(IRWSH,ICOLSH)
  TRMAT(IRWSH,ICOLSH) = FIXIT
4 CONTINUE
RETURN
2 IF (IPWSH.EQ.NCOND) GO TO 1
IRWSH = IRWSH + 1
GO TO 3
1 ISNFLG = 1
RETURN
END
BLOCK DATA
COMMON /COORDS/ XLOC,YLOC,YIMAGE,GMR
COMMON /INTGRS/ IRD,IWR,NCOND,NPSPP,ISNFLG,J2,IPIVOT
COMMON /COMPLX/ TRMAT,V,EFIELD
COMMON /CONSTS/ CONST,TPIK,ZERO,XMIN,XINC
COMMON /REALS / EMAG,XSCAN,PMAT
REAL XLOC(100)/100*0./,YLOC(100)/100*0./,YIMAGE(100)/100*0./
REAL PMAT(100,100)/10000*0./
REAL GMR(100)/100*0./
COMPLEX TRMAT(100,101)/10100*(0.,0.)/, V(100)/100*(0.,0.)/
DATA IRD,IWR,NCOND,NPSPP,ISNFLG,J2,IPIVOT /5,6,0,0,0,0,0/
COMPLEX CONST/(0.,0.)/
DATA TPIK,ZERO,XMIN,XINC/5.5606E-11,.000001,0.,0./
END

```

F. C. ACRE FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

FILE: FILE

FORTRAN A

OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITY LAB

```

RAT = TAUDB/20.00
TAU(I) = (10.000*RAT)
4 WRITE(16,4) I,TAU(I)
FORMAT(10X,'TAU (',I1,') =',F10.3,2X,'MICROAMP/SQRT H')
CONTINUE
C
C TO DETERMINE THE "GEOMETRIC MATRIX" OF THE PHASES
53 WRITE(6,53)
FORMAT(10X,5X,"VALUES OF GEOMETRIC MATRIX (G)")*
DO 30 I = 1,3
HT(I) = H
H(I) = -H
DO 30 J = 1,3
IF(I.EQ.J) GO TO 31
DW(I,J) = 0
IF(I.EQ.1.AND.J.EQ.3) DW(I,J) = 0*2.00
IF(I.EQ.3.AND.J.EQ.1) DW(I,J) = 0*2.00
D(I,J) = SQRT(HT(I)*HT(J)**2 + DW(I,J)**2)
G(I,J) = ALOG(DH(I,J)/DW(I,J))
G1 TO 30
G(I,J) = ALOG(2.00*HT(I)*100.00/A)
30 CONTINUE
WRITE(16,5) ((G(I,J),J=1,3),I=1,3)
FORMAT(5X,F10.3)
C
C TO DETERMINE THE "MODAL TRANSFORMATION MATRIX" OF THE PHASES
C NEED TO COMPUTE THE VALUES OF LAMBDA WHERE LAMBDA ARE THE CUBIC
C ROOTS FOR THE DETERMINANT OF "GEOMETRIC MATRIX" EQUAL ZERO
C * G11-LAM   G12   G13   *
C * G21       G22-LAM   G23   * = 0.0    (A)
C * G31       G32       G33-LAM   *
C
C OBTAIN THE CUBIC EQUATION AND SOLVE FOR LAMBDA (LAM)
C THE CUBIC EQUATION IS OF THE FORM
C LAM(CURE)+A1*LAM(SO)+A2*LAM+A3 = 0.0
C TO SOLVE FOR LAMBDA
C WRITE(6,55)
55 FORMAT(10X,5X,"VALUES OF LAMBDA")
C
A1 = -(G(1,1) + G(2,2) + G(3,3))
A2 = (G(1,1)*G(2,2) + G(1,1)*G(3,3) + G(2,2)*G(3,3)) -
    (G(1,2)*G(2,1) + G(3,2)*G(2,3) + G(1,3)*G(3,1))
A3 = (G(1,1)*G(3,2)*G(2,3) + G(1,2)*G(2,1)*G(3,3) +
2     G(1,3)*G(3,1)*G(2,2)) - (G(1,1)*G(2,2)*G(3,3) +
3     G(1,2)*G(3,1)*G(2,3) + G(1,3)*G(2,1)*G(3,2))
C
QG = (-1.00*A2 - A1*A1)/9.00
R = (9.00*A1*A2 - 27.00*A3 - 2.00*(A1**3))/54.00
THETA = ARCCOS(R/SQRT(-QG))
DO 40 I = 1,3
LAM(I) = 2.00*SQRT(-QG)*COS((THETA/3.00)+(FLOAT(I)-1.00)*120.00*PI/180.00)-A1/3.00
40 WRITE(16,7) I,LAM(I)
FORMAT(10X,"LAM (",I1,") =",F10.3)
CONTINUE

```

FILE: ACR1 FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITY LAB

```

C TO ARRANGE THE VALUES OF LAMBDAS IN ASCENDING ORDER          ACR01110
C WRITE (6,56)                                                 ACR01120
56 FORMAT('0',5X,'VALUES OF LAMBDAS IN ASCENDING ORDER')      ACR01130
C I = 3                                                       ACR01140
C NN = I-1                                                    ACR01150
C DO 60 K = 1,NN                                             ACR01160
C JJ = I-K                                                    ACR01170
C DO 70 L = I,JJ                                             ACR01180
C IF(LAM(L).LE.,LAM(L+1)) GO TO 70                           ACR01190
C TEMP = LAM(L)                                              ACR01200
C LAM(L) = LAM(L+1)                                           ACR01210
C LAM(L+1) = TEMP                                           ACR01220
70 CONTINUE                                                 ACR01230
60 CONTINUE                                                 ACR01240
C WRITE (6,8) (I,LAM(I),I=1,3)                                ACR01250
8  FORMAT(10X,'LAM (',I1,',') =',F10.3)                      ACR01260
C
C SUBSTITUTING EACH OF THESE VALUES OF LAMBDAS INTO EQUATION (A) ACR01270
C WILL GIVE US THE COLUMN OF THE "MODAL TRANSFORMATION MATRIX" (M) ACR01280
C WRITE (6,57)                                                 ACR01290
57 FORMAT('0',5X,'VALUES OF MODAL TRANSFORMATION MATRIX (M)') ACR01300
C FOR FIRST COLUMN                                         ACR01310
C DO 80 I = 1,3                                              ACR01320
80 G(1,I) = G(1,I) - LAM(I)                                 ACR01330
C M(1,1) = 1.00                                              ACR01340
C M(2,1) = M(1,1)                                            ACR01350
C M(3,1) = -M(1,1)                                           ACR01360
C M(2,1) = -(G(1,1)*M(1,1) + G(1,3)*M(3,1))/G(1,2)        ACR01370
C DIV1 = SQRT(M(1,1)**2 + M(2,1)**2 + M(3,1)**2)           ACR01380
C DO 81 I = 1,3                                              ACR01390
81 M(I,1) = M(I,1)/DIV1                                     ACR01400
C
C FOR SECOND COLUMN                                         ACR01410
C DO 998 I = 1,3                                             ACR01420
998 G(1,I) = G(1,I) + LAM(I) - LAM(2)                      ACR01430
C M(1,2) = -1.00                                             ACR01440
C M(3,2) = -M(1,2)                                           ACR01450
C M(2,2) = -(G(1,1)*M(1,2) + G(1,3)*M(3,2))/G(1,2)        ACR01460
C DIV2 = SQRT(M(1,2)**2 + M(2,2)**2 + M(3,2)**2)           ACR01470
C DO 997 I = 1,3                                             ACR01480
997 M(I,2) = M(I,2)/DIV2                                     ACR01490
C
C FOR THIRD COLUMN                                         ACR01500
C DO 82 I = 1,3                                              ACR01510
82 G(1,I) = G(1,I) + LAM(2) - LAM(3)                        ACR01520
C M(1,3) = 1.00                                              ACR01530
C M(3,3) = M(1,3)                                           ACR01540
C M(2,3) = -(G(1,1)*M(1,3) + G(1,3)*M(3,3))/G(1,2)        ACR01550
C DIV3 = SQRT(M(1,3)**2 + M(2,3)**2 + M(3,3)**2)           ACR01560
C DO 83 I = 1,3                                              ACR01570
83 M(I,3) = M(I,3)/DIV3                                     ACR01580
C
C WRITE (6,9) ((M(I,J),J=1,3),I=1,3)                         ACR01590
9  FORMAT(3(5X,F10.3))                                       ACR01600
C

```

FILE: ACR1 FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

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C      STEP 5
C      TO DETERMINE THE MODAL COMPONENTS OF CORONA CURRENT INJECTIONS
C      NEED TO FIND THE INVERSE MATRICES OF (G) AND (M)
C
C      TO FIND INVERSE MATRIX OF (G)  I.E. (G)-1
C      WRITE (6,58)
58   FORMAT(10F,5X,'VALUES OF INVERSE MATRIX OF (G)=')
DO 94 I = 1,3
94   GII,I) = GII,I) + LAME3I
      K = 1
      CALL INVERS (K,G,M,ZII)
DO 90 J = 1,3
DO 90 I = 1,3
90   GI1,I,J) = ZII,I,J)
      WRITE (6,12) ((GI1,I,J),J=1,3),I=1,3)
C
C      TO FIND INVERSE MATRIX OF (M)  I.E. (M)-1
C      WRITE (6,59)
59   FORMAT(10F,5X,'VALUES OF INVERSE MATRIX OF (M)=')
      K = 2
      CALL INVERS (K,G,M,ZII)
DO 91 J = 1,3
DO 91 I = 1,3
91   MI1,I,J) = ZII,I,J)
      WRITE (6,12) ((MI1,I,J),J=1,3),I=1,3)
12   FORMAT(3(5X,F10.3))
C
C      TO OBTAIN THE PRODUCT OF (G)-1* (M)
C      WRITE (6,61)
61   FORMAT(10F,5X,'VALUES OF PRODUCT OF (M)* (G)-1' )
DO 92 I = 1,3
DO 92 J = 1,3
92   GMII,J) = 0.0
DO 92 INDEX = 1,3
GMII,J) = GMII,J) + MII,INDEX)*GI1(INDEX,J)
92   CONTINUE
      WRITE (6,12) ((GMII,J),J=1,3),I=1,3)
C
C      ***** COMPUTATION FOR PHASE ONE ONLY *****
C      ***** COMPUTATION FOR PHASE ONE ONLY *****
C
C      TO OBTAIN THE VALUES OF THE CORONA CURRENT INJECTION JC ON
C      PHASE ONE
C      WRITE (6,14)
14   FORMAT(10F,5X,'VALUES OF CORONA CURRENT IN EACH MODE')
DO 93 I = 1,3
93   JCII,I) = GMII,I)*TAU(I)
      WRITE (6,99) (JCII,I),I=1,3)
99   FORMAT(15X,F10.3)
C
C      TO DETERMINE THE MODAL CURRENTS IN THE THREE CONDUCTORS FOR
C      PHASE ONE
C      WRITE (6,15)

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FILE: ACR1 FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

```

15  FORMAT(10X,'VALUES OF MODAL CURRENTS IN EACH CONDUCTOR')      ACR02210
    F = 200.00          ACR02220
    CALL CONST (V,F,ALPHA)          ACR02230
    DO 94 I = 1,3          ACR02240
94  IC21(I,I) = JC(I,I)/(2.00*SQRT(ALPHA(I)))          ACR02250
    WRITE (6,16) (I,IC21(I,I),I=1,3)          ACR02260
16  FORMAT(15X,'IC21 (*,II,',I) =',F10.3,2X,'MICROAMP')          ACR02270
C          ACR02280
    F = 500.00          ACR02290
    CALL CONST (V,F,ALPHA)          ACR02300
    DO 95 I = 1,3          ACR02310
95  IC51(I,I) = JC(I,I)/(2.00*SQRT(ALPHA(I)))          ACR02320
    WRITE (6,13) (I,IC51(I,I),I=1,3)          ACR02330
13  FORMAT(15X,'IC51 (*,II,',I) =',F10.3,2X,'MICROAMP')          ACR02340
C          ACR02350
C          TO DETERMINE THE PHASE CURRENTS IP(I,J)
C          FOR FREQUENCY AT 200 KHZ          ACR02360
    WRITE (6,71)          ACR02370
71  FORMAT(10X,'VALUES OF MODAL CURRENTS (MICROA) AT 200 KHZ')      ACR02380
    K = 1          ACR02390
    CALL IPHASE (M,K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP)      ACR02400
    DO 96 I = 1,3          ACR02410
    DO 96 J = 1,3          ACR02420
96  IP21(I,J) = IP(I,J)          ACR02430
    WRITE (6,12) ((IP21(I,J),J=1,3),I=1,3)          ACR02440
C          ACR02450
C          FOR FREQUENCY AT 500 KHZ          ACR02460
    WRITE (6,72)          ACR02470
72  FORMAT(10X,'VALUES OF MODAL CURRENTS (MICROA) AT 500 KHZ')      ACR02480
    K = 2          ACR02490
    CALL IPHASE (M,K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP)      ACR02500
    DO 97 I = 1,3          ACR02510
    DO 97 J = 1,3          ACR02520
97  IP51(I,J) = IP(I,J)          ACR02530
    WRITE (6,12) ((IP51(I,J),J=1,3),I=1,3)          ACR02540
C          ACR02550
C          =====
C          COMPUTATION FOR PHASE TWO ONLY          ACR02560
C          =====
C          WRITE (6,14)
    DO 22 I = 1,3          ACR02570
22  JC(I,I) = GM(I,2)*TAU(2)          ACR02580
    WRITE (6,99) (JC(I,I),I=1,3)          ACR02590
C          ACR02600
C          TO DETERMINE MODAL CURRENTS IN THE THREE CONDUCTORS          ACR02610
    WRITE (6,15)          ACR02620
    F = 200.00          ACR02630
    CALL CONST (V,F,ALPHA)          ACR02640
    DO 23 I = 1,3          ACR02650
23  IC22(I,I) = JC(I,I)/(2.00*SQRT(ALPHA(I)))          ACR02660
    WRITE (6,24) (I,IC22(I,I),I=1,3)          ACR02670
24  FORMAT(15X,'IC22 (*,II,',I) =',F10.3,2X,'MICROAMP')          ACR02680
C          ACR02690
C          ACR02700
C          ACR02710
C          ACR02720
C          ACR02730
C          ACR02740
C          ACR02750

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FILE: ACR1 FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

```

F = 500.00                                ACR02760
CALL CONSTIV,F,ALPHA)                      ACR02770
DO 25 I = 1,3                               ACR02780
25  IC52(I,1) = JC(I,1)/(2.00*SORT(ALPHA(I))) ACR02790
      WRITE (6,26) (I,IC52(I,1),I=1,3)          ACR02800
26  FORMAT(15X,'IC52 (',I1,',',I1,') =',F10.3,2X,'MICROAMP')
C
C TO DETERMINE THE PHASE CURRENTS          ACR02810
C FOR FREQUENCY AT 200 KHZ                 ACR02820
      WRITE (6,71)
      KK = 1                                  ACR02830
      CALL IPHASE (M,K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP) ACR02840
      DO 32 I = 1,3                           ACR02850
      DO 32 J = 1,3                           ACR02860
32  IP22(I,J) = IP(I,J)                     ACR02870
      WRITE (6,12) ((IP22(I,J),J=1,3),I=1,3) ACR02880
C
C FOR FREQUENCY AT 500 KHZ                 ACR02890
      WRITE (6,72)
      KK = 2                                  ACR02900
      CALL IPHASE (M,K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP) ACR02910
      DO 34 I = 1,3                           ACR02920
      DO 34 J = 1,3                           ACR02930
34  IP52(I,J) = IP(I,J)                     ACR02940
      WRITE (6,12) ((IP52(I,J),J=1,3),I=1,3) ACR02950
C
C ===== COMPUTATION FOR PHASE THREEF ONLY   ACR02960
C =====                                     ACR02970
C                                     ACR02980
C                                     ACR02990
C                                     ACR03000
C                                     ACR03010
C                                     ACR03020
C                                     ACR03030
C                                     ACR03040
C                                     ACR03050
C                                     ACR03060
C                                     ACR03070
C                                     ACR03080
101  JC(I,1) = GM(I,3)*TAU(3)                ACR03090
      WRITE (6,99) (JC(I,1),I=1,3)              ACR03100
C
C TO DETERMINE THE MODAL CURRENTS IN THE THREEF CONDUCTORS ACR03110
      WRITE (6,15)
      F = 200.00                                ACR03120
      CALL CONST (V,F,ALPHA)                      ACR03130
      DO 102 I = 1,3                           ACR03140
102  IC23(I,1) = JC(I,1)/(2.00*SORT(ALPHA(I))) ACR03150
      WRITE (6,103) (I,IC23(I,1),I=1,3)          ACR03160
103  FORMAT(15X,'IC23 (',I1,',',I1,') =',F10.3,2X,'MICROAMP')
C
C F = 500.00                                ACR03170
C CALL CONST (V,F,ALPHA)                      ACR03180
C DO 104 I = 1,3                           ACR03190
104  IC53(I,1) = JC(I,1)/(2.00*SORT(ALPHA(I))) ACR03200
      WRITE (6,105) (I,IC53(I,1),I=1,3)          ACR03210
105  FORMAT(15X,'IC53 (',I1,',',I1,') =',F10.3,2X,'MICROAMP')
C
C TO DETERMINE THE THE PHASE CURRENT          ACR03220
C FOR FREQUENCY AT 200 KHZ                  ACR03230
      WRITE (6,71)

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FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITY LAB

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      KKK = 1                                ACR03310
      CALL IPHASE (M,K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP)    ACR03320
      DO 106 I = 1,3                         ACR03330
      DO 106 J = 1,3                         ACR03340
106   IP23(I,J) = IP(I,J)                  ACR03350
      WRITE (6,121) ((IP23(I,J),J=1,3),I=1,3)    ACR03360
C
C      FOR FREQUENCY AT 500 KHZ             ACR03370
      WRITE (6,721)
      KKK = 2                                ACR03380
      CALL IPHASE (M,K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP)    ACR03390
      DO 107 I = 1,3                         ACR03400
      DO 107 J = 1,3                         ACR03410
107   IP53(I,J) = IP(I,J)                  ACR03420
      WRITE (6,121) ((IP53(I,J),J=1,3),I=1,3)    ACR03430
C
C      GO TO 700                            ACR03440
C
C      =====
C      PART (A) WILL COMPUTE THE RI NOISE LEVEL FROM THE AC TRANSMISSION ACR03450
C      LINES ALONG THE LATENT DISTANCE WITH THE RECEIVER ALTITUDE AT ACR03510
C      GROUND LEVEL.                      ACR03520
C      PART (B) WILL COMPUTE THE CRITICAL DISTANCES WHERE THE RATIO OF ACR03530
C      DESIRED SIGNAL (FROM NDA)/UNDESIRED NOISE (RI) IS 15 DB WITH THE ACR03540
C      RECEIVER ALTITUDES AT 500', 1000' AND 1500'.                 ACR03550
C      =====
C
C      PART (A)                            ACR03560
700   CONTINUE                               ACR03570
C
C      WITH KNOWN MODAL CURRENTS CALCULATED ABOVE THE RI NOISE AT ACR03580
C      GROUND LEVEL COULD BE DETERMINED NOW.                      ACR03590
C
C      FOR FREQUENCY AT 200 KHZ AND 500 KHZ ACR03600
      WRITE (6,621)                           ACR03610
62    FORMAT(*0*,T17,'YLOC',T30,'XLNC',T44,'EN200',T59,'EN500') ACR03620
C
C      TALT1 = 0                                ACR03630
      YLOC = FLOAT(TALT1)*0.3049            ACR03640
      XF = 500.00                             ACR03650
      XI = 0.0                                ACR03660
      NP = 100                                ACR03670
      XD = (XF-XI)/FLOAT(NP)                ACR03680
      XP = XI
      DO 77 I = 1,NP                         ACR03690
      XP = XP + XD                         ACR03700
      J = I+NP                                ACR03710
      XLNC = XP*0.3049                      ACR03720
C
      K=1
      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE) ACR03730
      EA2 = FE
      K=2
      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE) ACR03740
      EA5 = FE
C
      Y(I) = EA2                                ACR03750
                                         ACR03760
                                         ACR03770
                                         ACR03780
                                         ACR03790
                                         ACR03800
                                         ACR03810
                                         ACR03820
                                         ACR03830
                                         ACR03840
                                         ACR03850

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FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITY LAPI

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X(I) = XP          ACR03840
Y(I) = FAS         ACR03870
X(J) = XP         ACR03880
C
      WRITE (6,78) IALTI,X(I),Y(I),Y(J)
78  FORMAT(10X,L18,3F15.3)
77  CONTINUE
      CALL MPLOT(X,Y,NP,2,XL,YL)
      GO TO 999
C
C
C PART (B)
A00  CONTINUE
C LEFT HEIGHT OF ANTENNA BE 40'. K=1 IF FREQUENCY IS 200 KHZ AND
C K=2 IF FREQUENCY IS 500 KHZ
      WRITE (6,550)
550  FORMAT(*0*,T11,*DD(NM)*,T24,*D(0)*,T40,*D(500)*,T56,*D(1000)*,
2           T72,*D(1500)*)
C
      K = 2
      H1 = 40.00*0.3048
      XF = 20.00
      XI = 0.00
      NP = 20
      DX = (XF-XI)/FLOAT(NP)
      XP = XI
      DO 400 J = 1,NP
      XP = XP+DX
      J = J+NP
      L = J+NP
      N = L+NP
      GO TO 505
C
      GO TO 505
C FOR RECEIVER ALTITUDE AT GROUND LEVEL (H2=0.0*)
      DO 500 INC = 1,10000
      CALL SIGNAL (INC,K,XP,H1,H2,PI,EPST,SIGMA,ERP,C,EFS)
      SIG1 = FFS
      YLOC = H2
      XLOC = FLOAT(INC)*0.3048
      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
      RINI = EE
      DELTA1 = SIG1-RINI
      IF(DELTA1.GE.15.00) GO TO 600
500  CONTINUE
      DIST1 = FLOAT(INC)
C
505  CONTINUE
C FOR RECEIVER ALTITUDE AT 500' (H2=500.0*)
      H2 = 500.00*0.3048
      DO 501 INC = 1,10000,10
      CALL SIGNAL (INC,K,XP,H1,H2,PI,EPST,SIGMA,ERP,C,EFS)
      SIG2 = FFS
      YLOC = H2
      XLOC = FLOAT(INC)*0.3048
      CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)
      
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FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

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RIN2 = EE                                ACR04410
DELTA2 = SIG2-RIN2                         ACR04420
IF(DELTA2.GE.15.00) GO TO 601             ACR04430
501 CONTINUE                               ACR04440
601 DIST2 = FLOAT(INC)                     ACR04450
C                                         ACR04460
C FOR RECEIVER ALTITUDE AT 1000° (H2=1000°)   ACR04470
H2 = 1000.00*0.3049                        ACR04480
DO 502 INC = 1,10000,10                      ACR04490
CALL SIGNAL (INC,K,XP,HL,H2,PI,EPST,SIGMA,ERP,C,EFS) ACR04500
SIG3 = EFS                                 ACR04510
YLOC = H2                                  ACR04520
ACR04530
XLOC = FLOAT(INC)*0.3049                  ACR04540
CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE) ACR04550
RIN3 = EE                                  ACR04560
DELTA3 = SIG3-RIN3                         ACR04570
IF(DELTA3.GE.15.00) GO TO 602             ACR04580
502 CONTINUE                               ACR04590
602 DIST3 = FLOAT(INC)                     ACR04600
C                                         ACR04610
C FOR RECEIVER ALTITUDE AT 1500° (H2=1500°)   ACR04620
H2 = 1500.00*0.3049                        ACR04630
DO 503 INC = 1,10000,10                      ACR04640
CALL SIGNAL (INC,K,XP,HL,H2,PI,EPST,SIGMA,ERP,C,EFS) ACR04650
SIG4 = EFS                                 ACR04660
YLOC = H2                                  ACR04670
ACR04680
XLOC = FLOAT(INC)*0.3049                  ACR04690
CALL NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE) ACR04700
RIN4 = EE                                  ACR04710
DELTA4 = SIG4-RIN4                         ACR04720
IF(DELTA4.GE.15.00) GO TO 603             ACR04730
503 CONTINUE                               ACR04740
603 DIST4 = FLOAT(INC)                     ACR04750
C                                         ACR04760
C                                         ACR04770
Y(I) = XP                                 ACR04780
X(I) = DIST1                            ACR04790
Y(J) = XP                                 ACR04800
X(J) = DIST2                            ACR04810
Y(L) = XP                                 ACR04820
X(L) = DIST3                            ACR04830
Y(N) = XP                                 ACR04840
X(N) = DIST4                            ACR04850
C                                         ACR04860
C                                         ACR04870
WRITE (6,401) Y(I),X(J),X(L),X(N),SEG2,RIN2,SIG3,RIN3 ACR04880
401 FORMAT(8F8.1)                           ACR04890
400 CONTINUE                               ACR04900
C                                         ACR04910
C                                         ACR04920
CALL MPLOT (X,Y,NP,4,XL,YL)               ACR04930
WRITE (6,199) K,ERP                         ACR04940
199 FORMAT(5X,T5,F10.3)                   ACR04950
C                                         ACR04960
C                                         ACR04970
GO TO 2000                                ACR04980
C                                         ACR04990
900 CONTINUE                               ACR05000

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FILE: ACR1 FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

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C THIS PART WILL COMPUTE THE RI NOISE AT ANY POINT OF          ACR04960
C OBSERVATION.                                                 ACR04970
C K = 2                                                       ACR04980
C KK = 2                                                       ACR04990
DO 1000 I = 2,600,KK                                     ACR05000
IF(I1.GE.100) KK = 25                                     ACR05010
XLNC = FLOAT(I)*0.3049                                    ACR05020
ACR05030
ACR05040
ACR05050
ACR05060
ACR05070
ACR05080
ACR05090
ACR05100
ACR05110
ACR05120
ACR05130
ACR05140
ACR05150
ACR05160
ACR05170
ACR05180
ACR05190
ACR05200
ACR05210
ACR05220
ACR05230
ACR05240
ACR05250
ACR05260
ACR05270
ACR05280
ACR05290
ACR05300
ACR05310
ACR05320
ACR05330
ACR05340
ACR05350
ACR05360
ACR05370
ACR05380
ACR05390
ACR05400
ACR05410
ACR05420
ACR05430
ACR05440
ACR05450
ACR05460
ACR05470
ACR05480
ACR05490
ACR05500

```

C H2 = 000.00*0.3049

C YLNC = H2

C CALL NOISE (K,XLNC,YLNC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)

C E0 = EE

C H2 = 500.00*0.3049

C YLNC = H2

C CALL NOISE (K,XLNC,YLNC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)

C E500 = EE

C H2 = 1000.00*0.3049

C YLNC = H2

C CALL NOISE (K,XLNC,YLNC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)

C E1000 = EE

C YLNC = 1500.00*0.3049

C CALL NOISE (K,XLNC,YLNC,H,D,IP21,IP51,IP22,IP52,IP23,IP53,EE)

C E1500 = EE

C WRITE (6,1200) I,E0,E500,E1000,E1500

1200 FORMAT (5X,15.4F10.3)

1000 CONTINUE

2000 CONTINUE

STOP

END

C SUBROUTINE INVERS (K,G,4,Z)

DIMENSION G(30,30),Z(30,30),ZI(30,30),ZC(30,30),ZA(30,30)

REAL M(30,30)

DO 9 J = 1,3

DO 9 I = 1,3

IF(K.EQ.1) Z(I,J) = G(I,J)

IF(K.EQ.2) Z(I,J) = M(I,J)

9 CONTINUE

C TO OBTAIN COFACTOR MATRIX (ZC)

ZC(1,1) = +(Z(2,2)*Z(3,3)-Z(3,2)*Z(2,3))

ZC(1,2) = -(Z(2,1)*Z(3,3)-Z(3,1)*Z(2,3))

ZC(1,3) = +(Z(2,1)*Z(3,2)-Z(3,1)*Z(2,2))

C ZC(2,1) = -(Z(1,2)*Z(3,3)-Z(3,2)*Z(1,3))

ZC(2,2) = +(Z(1,1)*Z(3,3)-Z(3,1)*Z(1,3))

ZC(2,3) = -(Z(1,1)*Z(3,2)-Z(3,1)*Z(1,2))

C ZC(3,1) = +(Z(1,2)*Z(2,3)-Z(2,2)*Z(1,3))

ZC(3,2) = -(Z(1,1)*Z(2,3)-Z(2,1)*Z(1,3))

FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

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      ZC(3,3) = +(Z(1,1)*Z(2,2)-Z(2,1)*Z(1,2))          ACR05510
C      TO OBTAIN ADJOINT MATRIX (ZA)                      ACR05520
      DO 1 J = 1,3                                       ACR05530
      DO 1 I = 1,3                                       ACR05540
1     ZA(I,J) = ZC(J,I)                                 ACR05550
C      TO DETERMINE THE VALUE OF DETERMINANT OF (Z)
      DET = (Z(1,1)*(Z(2,2)*Z(3,3)-Z(3,2)*Z(2,3)))
2     -(Z(1,2)*(Z(2,1)*Z(3,3)-Z(3,1)*Z(2,3)))
3     +(Z(1,3)*(Z(2,1)*Z(3,2)-Z(3,1)*Z(2,2)))          ACR05560
C      TO OBTAIN INVERSE MATRIX OF (Z)
      DO 2 J = 1,3                                       ACR05570
      DO 2 I = 1,3                                       ACR05580
2     ZA(I,J) = ZA(I,J)/DET                           ACR05590
      RETURN                                              ACR05600
      END                                                 ACR05610
C      SUBROUTINE CONST (V,F,ALPHA)
C      ALPHAS DEPEND ON FREQUENCY IN MHZ AND GROUND RESISTIVITY IN
C      OHM.M. UNDER HEAVY RAIN CONDITION GROUND RESISTIVITY IS 75.0 OHM.M.
C      DIMENSION ALPHA (10),VLINE(10),BETA(30)           ACR05620
      F = F/1.00E3                                      ACR05630
C      TO FIND THE VOLTAGE CLASS
      VLINE(1) = 362.00                                 ACR05640
      VLINE(2) = 550.00                                 ACR05650
      VLINE(3) = 800.00                                 ACR05660
      VLINE(4) = 1200.0                                 ACR05670
      DO 1 I = 1,4                                     ACR05680
      DELTA = VLINE(I) - V                            ACR05690
      IF(DELTA.GE.10.00) GO TO 2                      ACR05700
1     CONTINUE                                         ACR05710
2     IF(I.EQ.1) GO TO 3                            ACR05720
      IF(I.EQ.2) GO TO 4                            ACR05730
      IF(I.EQ.3) GO TO 5                            ACR05740
      IF(I.EQ.4) GO TO 6                            ACR05750
3     BETA(1) = 8.00E-6                           ACR05760
      BETA(2) = 60.00E-6                           ACR05770
      BETA(3) = 350.00E-6                          ACR05780
      GO TO 7                                         ACR05790
4     BETA(1) = 9.30E-6                           ACR05800
      BETA(2) = 70.00E-6                           ACR05810
      BETA(3) = 350.00E-6                          ACR05820
      GO TO 7                                         ACR05830
5     BETA(1) = 10.00E-6                          ACR05840
      BETA(2) = 70.00E-6                           ACR05850
      BETA(3) = 350.00E-6                          ACR05860
      GO TO 7                                         ACR05870
6     BETA(1) = 10.60E-6                          ACR05880
      BETA(2) = 84.00E-6                           ACR05890
      BETA(3) = 350.00E-6                          ACR05900
      GO TO 7                                         ACR05910
7     CONTINUE                                         ACR05920
      DO 8 I = 1,3                                     ACR05930

```

FILE: ACR1 FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LABO

```

8     ALPHA(I) = (F**0.8)*SQR(0.750)*BETA(I)          ACR06060
      WRITE (6,9)
9     FORMAT("0",10X,"VALUES OF ALPHAS")
      WRITE (6,10) (I,ALPHA(I),I=1,3)                  ACR06070
10    FORMAT(10X,'ALPHA ('',I'',') =',G10.3)
      RETURN
      END
C
SUBROUTINE IPHASE (K,KK,KKK,IC21,IC51,IC22,IC52,IC23,IC53,IP) ACR06140
REAL IC1(20,20),M(30,30),IC21(20,20),IC51(20,20),IP(20,20) ACR06150
REAL IC22(20,20),IC52(20,20) ACR06160
REAL IC23(20,20),IC53(20,20) ACR06170
REAL MA(30,30) ACR06180
DO I J = 1,3 ACR06190
DO 1 I = 1,3 ACR06200
DO 2 I = 1,3 ACR06210
IF(K.EQ.1) IC(I,I) = IC21(I,I) ACR06220
IF(K.EQ.2) IC(I,I) = IC51(I,I) ACR06230
IF(KK.EQ.1) IC(I,I) = IC22(I,I) ACR06240
IF(KK.EQ.2) IC(I,I) = IC52(I,I) ACR06250
IF(KKK.EQ.1) IC(I,I) = IC23(I,I) ACR06260
IF(KKK.EQ.2) IC(I,I) = IC53(I,I) ACR06270
2 CONTINUE ACR06280
DO 3 I = 1,3 ACR06290
DO 3 J = 1,3 ACR06300
3 IP(I,J) = MA(I,J)*IC(I,J) ACR06310
      RETURN ACR06320
      END
ACR06330
ACR06340
ACR06350
ACR06360
ACR06370
C
SUBROUTINE NOISE (K,XLOC,YLOC,H,D,IP21,IP51,IP22,IP52,IP23,IP53, E1)
REAL IP1(20,20),IP2(20,20),IP3(20,20) ACR06380
REAL IP21(30,30),IP51(30,30) ACR06390
REAL IP22(20,20),IP52(20,20),IP23(20,20),IP53(20,20) ACR06400
DIMENSION FF(30,30),FL(20,20),E2(20,20),E3(20,20) ACR06410
ACR06420
DO 1 J = 1,3 ACR06430
DO 1 I = 1,3 ACR06440
IF(K.EQ.1) GO TO 10 ACR06450
IF(K.EQ.2) GO TO 11 ACR06460
10   IP1(I,J) = IP21(I,J) ACR06470
      IP2(I,J) = IP22(I,J) ACR06480
      IP3(I,J) = IP23(I,J) ACR06490
      GO TO 1 ACR06500
11   IP1(I,J) = IP51(I,J) ACR06510
      IP2(I,J) = IP52(I,J) ACR06520
      IP3(I,J) = IP53(I,J) ACR06530
      CONTINUE ACR06540
C
X = XLOC ACR06550
Y = X+D ACR06560
Z = X-D ACR06570
W = YLOC+H ACR06580
U = YLOC-H ACR06590
C

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FILE: ACR1 FORTRAN OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

```

FY1 = 60.00*((W/(Y*Y + W*W)) - (U/(Y*Y + U*U)))      ACR06610
FX1 = 60.00*Y*((1.00/(Y*Y + U*U)) - (1.00/(Y*Y + W*W))) ACR06620
FF(1,1) = SQRT(FY1*FY1 + FX1*FX1)                         ACR06630
C
FY2 = 60.00*((W/(X*X + W*W)) - (U/(X*X + U*U)))      ACR06640
FX2 = 60.00*Y*((1.00/(X*X + U*U)) - (1.00/(X*X + W*W))) ACR06650
FF(2,1) = SQRT(FY2*FY2 + FX2*FX2)                         ACR06660
C
FY3 = 60.00*((W/(Z*Z + W*W)) - (U/(Z*Z + U*U)))      ACR06670
FX3 = 60.00*Z*((1.00/(Z*Z + U*U)) - (1.00/(Z*Z + W*W))) ACR06680
FF(3,1) = SQRT(FY3*FY3 + FX3*FX3)                         ACR06690
C
C TO MULTIPLY THE MODAL PHASE CURRENTS WITH THE FIELD FACTORS   ACR06700
C FF(I,J) TO OBTAIN THE RT NOISE LEVEL IN MICROV/M             ACR06710
DO 2 I = 1,3
J = 1
E1(I,J) = 0.0
DO 2 INDEX = 1,3
2 E1(I,J) = E1(I,J) + IP1(I,INDEX)*FF(INDEX,J)
C
DO 3 I = 1,3
J = 1
E2(I,J) = 0.0
DO 3 INDEX = 1,3
3 E2(I,J) = E2(I,J) + IP2(I,INDEX)*FF(INDEX,J)
C
DO 4 I = 1,3
J = 1
E3(I,J) = 0.0
DO 4 INDEX = 1,3
4 E3(I,J) = E3(I,J) + IP3(I,INDEX)*FF(INDEX,J)
C
EE1 = 0.0
J = 1
DO 5 I = 1,3
5 EE1 = EE1 + SORT(E1(I,J)*E1(I,J))
C
EE2 = 0.0
J = 1
DO 6 I = 1,3
6 EE2 = EE2 + SORT(E2(I,J)*E2(I,J))
C
EE3 = 0.0
J = 1
DO 7 I = 1,3
7 EE3 = EE3 + SORT(E3(I,J)*E3(I,J))
C
ETOT = SQRT(EE1*EE1 + EE2*EE2 + EE3*EE3)
EE = 20.00* ALOG10(ETOT)
RETURN
END
C
SUBROUTINE SIGNAL (INC,K,XP,HI,H2,PI,EPSI,SIGMA,ERP,C,EFSI
REAL LAMBDA
COMPLEX ETA,DELTA,Q,RHO,ERF,ERFC,T,TT,A
ACR06720
ACR06730
ACR06740
ACR06750
ACR06760
ACR06770
ACR06780
ACR06790
ACR06800
ACR06810
ACR06820
ACR06830
ACR06840
ACR06850
ACR06860
ACR06870
ACR06880
ACR06890
ACR06900
ACR06910
ACR06920
ACR06930
ACR06940
ACR06950
ACR06960
ACR06970
ACR06980
ACR06990
ACR07000
ACR07010
ACR07020
ACR07030
ACR07040
ACR07050
ACR07060
ACR07070
ACR07080
ACR07090
ACR07100
ACR07110
ACR07120
ACR07130
ACR07140
ACR07150

```

FILE: ACRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LABO

```

COMPLEX Z,Z1,Z2,Z3,Z4                                ACR07160
IF(K.EQ.1) F = 200.00                                ACR07170
IF(K.EQ.2) F = 500.00                                ACR07180
C
EE = -1.800E7*SIGMA/F                                ACR07190
ETA = CMPLX(EPSI,EF)
DELTA = CSORT(ETA-1.00)/ETA
LAMBDA = C/(F*1.00E3)
CK = 2.00*PI/LAMBDA
ACR07200
ACR07210
ACR07220
ACR07230
ACR07240
ACR07250
ACR07260
ACR07270
ACR07280
ACR07290
ACR07300
ACR07310
ACR07320
ACR07330
ACR07340
ACR07350
ACR07360
ACR07370
ACR07380
ACR07390
ACR07400
ACR07410
ACR07420
ACR07430
ACR07440
ACR07450
ACR07460
ACR07470
C
R = XP*1852.00 + FLOAT(INC)*0.3049
DD = SQRT(R*R + (H1-H2)**2)
RR = SQRT(PI*CK*DD/2.00)
OO = PI/4.00
Q = CMPLX(0.00,OO)
RHO = CEXP(I)*RR
C
Z = CEXP(Q)*SQRT(CK*DD/2.00)*DELTA*(1.00+((H1+H2)/(DELTA+OO)))
Z1 = Z
Z2 = (Z**3)/(15.0*1.0)
Z3 = (Z**5)/(15.0*2.0*1.0)
Z4 = (Z**7)/(15.0*3.0*2.0*1.0)
ERF = (Z1-Z2-Z3-Z4)*(2.00/SQRT(PI))
ERFC = 1.000-ERF
C
T = Z*Z
TT = CEXP(T)
A = 1.00-(RHO*DELTA*TT*ERFC)
ES = (9.487*SQRT(ERF)/(R))*CABS(A)+1.00E6
EFS = 20.00*ALOG10(ES)
RETURN
END

```

FILE - SIGNAL FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

```

C      TO COMPUTE THE SIGNAL STRENGTH OF AN NOR TRANSMITTER          SIG00010
C GROUND CONDUCTIVITY IS 10 MMHO/M                                     SIG00020
C RELATIVE PERMITTIVITY IS 10                                         SIG00030
C EFFECTIVE RADIATED POWER IS 1 KW                                    SIG00040
C
C      DIMENSION Y(200),XL(200),YL(12),XL(12)                      SIG00050
C      DATA YL/'S1','T1','G1','N1','A1','L1','I1','T2','N2','D1','B1'/ SIG00060
C      DATA XL/'D1','I1','S1','T1','I1','I1','N1','D1','B1','N1','M1'/ SIG00070
C      COMPLEX FTA,DEL,Q,P,D,Z,ERF,ERFC,T,TT,A                         SIG00080
C      COMPLEX Z1,Z2,Z3,Z4                                              SIG00090
C
C      DATA PI,E,SIG,P,C/3.1416,10.0,0.010,10.00,3.0E8/                 SIG00100
C
C      WRITE (6,20)                                                 SIG00110
20   FORMAT('1',T20,'DIST(NM)',T35,'ESDR(200)',T50,'ESDR(500)')    SIG00120
C
C      XF = 100.0                                         SIG00130
C      XI = 0.0                                           SIG00140
C      NP = 100.0                                         SIG00150
C      DX = (XF-XI)/FLOAT(NP)                                SIG00160
C      D = XI                                             SIG00170
C      DO 1 I = 1,NP                                      SIG00180
C      D = D+DX                                         SIG00190
C      J = I + 100                                       SIG00200
C      H1 = 40.0E0.3049                                  SIG00210
C      H = 0000.0                                         SIG00220
C      H2 = H*0.3049                                     SIG00230
C
C      FOR FREQ OF 200 KHZ                                     SIG00240
C
C      F = 200.0                                         SIG00250
C      FE = -1.8E7*SIG/F                                 SIG00260
C      FTA = CMPLX(E,FE)                                 SIG00270
C
C      DEL = CSQRT(ETA-1.0)/FTA                            SIG00280
C
C      WL = C/(F*1.0E3)                                 SIG00290
C      CK = 2.0*PI/WL                                   SIG00300
C      DD = SORT((0*1852.0)*2 + ((H1-H2)*2)           SIG00310
C      PR = SORT(P*CK*DD/2.0)                           SIG00320
C      QD = PI/4.0                                       SIG00330
C      Q = CHPLX(0.0,0.0)                               SIG00340
C      PD = CEXP(Q)*RR                                 SIG00350
C
C      T = CEXP(I*1)*SORT(CK*DD/2.0)*DEL*(1.0+((H1+H2)/(DEL*DD))) SIG00360
C
C      TO COMPUTE THE ERFC(Z)                                SIG00370
C
C      Z1 = Z                                              SIG00380
C      Z2 = (Z**3)/(3.0*1.0)                             SIG00390
C      Z3 = (Z**5)/(15.0*2.0*1.0)                        SIG00400
C      Z4 = (Z**7)/(105.0*3.0*2.0*1.0)                   SIG00410
C
C      ERF = (Z1-Z2+Z3-Z4)*(2.0/SORT(P))                SIG00420
C
C      SIG00430
C      SIG00440
C      SIG00450
C      SIG00460
C      SIG00470
C      SIG00480
C      SIG00490
C      SIG00500
C      SIG00510
C      SIG00520
C      SIG00530
C      SIG00540
C      SIG00550

```

FILE: SIGNAL FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LABO

```

      ERFC = 1.0-ERF          SIG00560
C      T = 2*Z                SIG00570
C      TT = CEXP(T)           SIG00580
C      A = 1.0-(T*0.001*DEL*TT*ERFC) SIG00590
C      E1 = (9.487*SQRT(P)/(D*1.052.0))*CABS(A)*1.0E6 SIG00600
C
C      FOR FREQ OF 500 KHZ
C
C      F1 = F + 300.0          SIG00610
C      FEL = -1.0E7*SIG/F1    SIG00620
C      FTA = CMPLX(E,E1)      SIG00630
C
C      DEL = CSQRT(ETA-1.0)/ETA SIG00640
C
C      WL = C/(F1*1.0E3)      SIG00650
C      CK = 2.0*PI/WL         SIG00660
C      DD = SQRT((D*1.052.0)**2 + (H1-H2)**2) SIG00670
C      RR = SQRT(P1*CK*DD/2.0) SIG00680
C      OO = P1/6.0             SIG00690
C      Q = CMPLX(D,0,OO)      SIG00700
C      PO = CEXP(Q)*RR         SIG00710
C
C      Z = CEXP(Q)*SQRT(CK*DD/2.0)*DEL*(1.0+(H1+H2)/(I*DEL*DD)) SIG00720
C
C      Z1 = 7                  SIG00730
C      Z2 = (Z*0.3)/(3.0*1.0)   SIG00740
C      Z3 = (Z*0.5)/(5.0*2.0*1.0) SIG00750
C      Z4 = (Z*0.7)/(7.0*3.0*2.0*1.0) SIG00760
C
C      ERF = (Z1-Z2-Z3-Z4)*(2.0/SQRT(P1)) SIG00770
C      ERFC = 1.0-ERF          SIG00780
C
C      T = 2*Z                SIG00790
C      TT = CEXP(T)           SIG00800
C      A = 1.0-(T*0.001*DEL*TT*ERFC) SIG00810
C
C      E2 = (9.487*SQRT(P)/(D*1.052.0))*CABS(A)*1.0E6 SIG00820
C
C      V(I) = 20.0*ALOG10(E1) SIG00830
C      X(I) = D                SIG00840
C      V(J) = 20.0*ALOG10(E2) SIG00850
C      X(J) = D                SIG00860
C
C      WRITE (6,101) X(I),V(I),V(J) SIG00870
10     FORMAT(10X,3F15.9)       SIG00880
1      CONTINUE                 SIG00890
      CALL MPLOT(X,Y,100,2,WL,V1) SIG01000
C
C      WRITE (6,99) H           SIG01010
99     FORMAT("0",10X,"REC. HEIGHT =",F10.9) SIG01020
      STOP                      SIG01030
      END                       SIG01040
                                SIG01050
                                SIG01060
                                SIG01070
                                SIG01080
                                SIG01090
                                SIG01100

```

FILE: DCR1 FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LABI

```

C TO COMPUTE THE RI NOISE OF THE DC-LINE WITH THE POINT
C OF OBSERVANCE AT ANY LOCATION. DCR00010
DCR00020
DCR00030
DCR00040
DCR00050
DCR00060
DCR00070
DCR00080
DCR00090
DCR00100
DCR00110
DCR00120
DCR00130
DCR00140
DCR00150
DCR00160
DCR00170
DCR00180
DCR00190
DCR00200
DCR00210
DCR00220
DCR00230
DCR00240
DCR00250
DCR00260
DCR00270
DCR00280
DCR00290
DCR00300
DCR00310
DCR00320
DCR00330
DCR00340
DCR00350
DCR00360
DCR00370
DCR00380
DCR00390
DCR00400
DCR00410
DCR00420
DCR00430
DCR00440
DCR00450
DCR00460
DCR00470
DCR00480
DCR00490
DCR00500
DCR00510
DCR00520
DCR00530
DCR00540
DCR00550

```

C CONSIDER ONLY THE POSITIVE POLE OF THE BI-POLAR AS
C THE NEGATIVE POLE GIVES A NEGLIGIBLE RI LEVEL.

C DIMENSION Y(200),X(200),YL(12),XL(12)
DATA YL/, 'R', 'T', ' ', 'L', 'V', 'E', 'L', ' ', 'D', 'B'/
DATA XL/'D', 'T', 'S', 'T', ' ', 'T', 'N', ' ', 'F', 'E', 'E', 'T'/
DATA PI,V,F/3.1416,600.0,200.0/
DATA NSUR,RAD,B,H,S/4,1.525,45.7,49.85,36.73/
C ENDRI(E1) = E1
ENDR2(E2) = E2
ENDR3(E3) = E3
ENDR4(E4) = E4
C TO DETERMINE THE MAXIMUM SURFACE GRADIENT.
C R = R/(2.0*SIN(PI/FLOAT(NSUR)))
A = 1.0/FLOAT(NSUR)
N = NSUR-1
P = (FLOAT(NSUR)*RAD*(R**N))**4
Q = SORT(((2.0*H/S)**2) + L-0)
GG = 2.0*H*0.3049*100.0/(P*Q)
G = (1.0 + (FLOAT(N)*RAD/R))/(FLOAT(NSUR)*RAD* ALOG(GG))
C GMAX = G*V
C
I WRITE (6,19 F,V,NSUR,RAD,B,H,S,GMAX
FORMAT('1',20X,'FREQ(KHZ)=',F10.3//21X,'VOLTAGE(+E-KV)=',
6 F10.3//21X,'NSUR=',I4//21X,'RADIOUS OF SUR (CM)=',
6 F10.4//21X,'B (CM)=',F10.3//21X,'AVE HEIGHT (FT)=',
6 ,F10.3//21X,'POLE-POLE (FT) =',F10.3//21X,
6 'G (KV/CM/KV) =',F10.4//21X,'GMAX (KV/CM) =',
6 ,F10.4//)
C TO COMPUTE THE RI AT GROUND LEVEL AND FROM THERE TO
C DETERMINE THE TOTAL CURRENT IN THE CONDUCTOR. THEN
C USE THE SURROUNTING HEIGHT TO COMPUTE THE RI AT ANY LOCATION.
C
4 WRITE (6,4)
FORMAT(1I1,'DIST(FT)',T24,'HP(0.0FT)',T36,'HP(250FT)',+
6 'T49,'HP(500FT)',T60,'HP(1000FT)'/)
C
XF = 500.0
XI = 0.0
NP = 50
DX = (XF-XI)/FLOAT(NP)
D = XI
DO 2 I = 1,NP
D = D + DX

FILE: NCR1 FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

```

J = I + 50          DCR00560
K = J + 50          DCR00570
L = K + 50          DCR00580
DCR00590
DCR00600
DCR00610
DCR00620
DCR00630
DCR00640
DCR00650
DCR00660
DCR00670
DCR00680
DCR00690
DCR00700
DCR00710
DCR00720
DCR00730
DCR00740
DCR00750
DCR00760
DCR00770
DCR00780
DCR00790
DCR00800
DCR00810
DCR00820
DCR00830
DCR00840
DCR00850
DCR00860
DCR00870
DCR00880
DCR00890
DCR00900
DCR00910
DCR00920
DCR00930
DCR00940
DCR00950
DCR00960
DCR00970
DCR00980
DCR00990
DCR01000
DCR01010
DCR01020
DCR01030
DCR01040
DCR01050
DCR01060
DCR01070
DCR01080
DCR01090
DCR01100

```

C
C GRAT = GMAX/14.00
C DRAD = SQRT(H*H+D*D)*0.3049
C
C E = 214.0* ALOG10(GRAT) - 278.0*ALOG10(GRAT)*ALOG10(GRAT)
2 + 40.0*ALOG10(RAD) + 27.0*ALOG10(834.0/F)
3 + 40.0*ALOG10(30.5/DRAD)
C
C TO COMPUTE THE RI NOISE AT DIFFERENT HEIGHT ABOVE GROUND
C AT THE HEIGHT OF 0 FT.
C HP = 0.0
C CALL HEIGHT (E,H,HP,D,PI,EH)
E1 = EH
C
C AT THE HEIGHT OF 500 FT.
C HP = 250.0
C CALL HEIGHT (E,H,HP,D,PI,EH)
E2 = EH
C
C AT THE HEIGHT OF 1000 FT.
C HP = 500.0
C CALL HEIGHT (E,H,HP,D,PI,EH)
E3 = EH
C
C AT THE HEIGHT OF 5000 FT.
C HP = 1000.0
C CALL HEIGHT (E,H,HP,D,PI,EH)
E4 = EH
C
C Y(I) = ENDR1(F1)
X(I) = D
Y(J) = ENDR2(E2)
X(J) = D
Y(K) = ENDR3(E3)
X(K) = D
Y(L) = ENDR4(E4)
X(L) = D
C
C WRITE (6,3) X(I),Y(I),Y(J),Y(K),Y(L)
3 FORMAT(5X,5F12.3)
2 CONTINUE
CALL M40LOT (X,Y,50,4,XL,YL)
STOP
END
C
C TO PUT IN SUBROUTINE HEIGHT
C
SUBROUTINE HEIGHT (E,H,HP,D,PI,EH)

FILE: DCRI FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPATABILITIES LAB

```

C      E IS IN DB/MICV/M          DCR01110
C      EE IS IN MICV/M          DCR01120
C
C      RAT = E/20.0              DCR01130
C      EE = 10.0*RAT             DCR01140
C
C      TO GET CURRENT.          DCR01150
C      CURR = EE*((H*0.3049)**2 + (D*0.3049)**2)/(60.0*2.0* DCR01160
C      6           H*0.3049)       DCR01170
C
C      NOW USE CURRENT TO COMPUTE H-FIELD AT ANY POINT. DCR01180
C
C      P = (HP+H)*0.3049          DCR01190
C      Q = (HP-H)*0.3049          DCR01200
C      DD = D*0.3049              DCR01210
C
C      HX = (CURR/(2.0*P))*((P/(DD*DD + P*P)) - (Q/(DD*DD + Q*Q))) DCR01220
C      HY = (CURR*DD/(2.0*P))*((1.0/(DD*DD + Q*Q)) - (1.0/ DCR01230
C      6           (DD*DD + P*P)))          DCR01240
C
C      FX = 120.0*P*HX            DCR01250
C      EY = 120.0*P*HY            DCR01260
C      EHP = SQRT(FX*FX + EY*EY)          DCR01270
C      EH = 20.0* ALOG10(EHP)          DCR01280
C      RETURN                      DCR01290
C      END                         DCR01300

```

FILE: PJRICH FORTRAN A OHIO UNIVERSITY ELECTROMAGNETIC COMPUTATIONAL LAB

```

IMPLICIT REAL*8(A-H,O-Z,S)
REAL*8 XH,XARL(100),YARL(100),XARL(12),YARL(12)
COMPLEX*16 EP2,EP3,ETA,GAM,Y11,Z11,ZS
COMPLEX*16 FUX,FUY,FUZ
COMPLEX*16 FPSS,FPSTS,FTTS,FX,FY,E7,UPLD
COMPLEX*16 C((4095),CJ(901),EP(901),ET(901),FPS(901),FTT(901)
DIMENSION I1(901),I2(901),I3(901),JA(901),JB(901)
COMPLEX*16 CGD(199),SGD(99),FG(198),VG1(198),ZLD(199)
DIMENSION D(99),IA(99),IB(99),IS(99),ID(99,4),ND(99)
DIMENSION X(110),Y(110),Z(110)
DATA PI,TP/3.14159265358979,6.28318530717958/
DATA EO,EOZR/4.54E-12,L2566E-6/
C
C FOR THE PLOT
DATA XARL/*M*,*A*,*G*,*  *  *,*  *,*N*,*  *,*  *,*F*,*T*/'
DATA YARL/*M*,*A*,*G*,*  *  *,*  *,*N*,*  *,*  *,*D*,*R*,*  */'
C
2 FORMAT(1X,8F10.4)
3 FORMAT(1X,4F10.4/)
4 FORMAT(1X,1I5,8F10.4)
5 FORMAT(1HO)
6 FORMAT(1X,6F10.4/)
7 FORMAT(9F10.5)
8 FORMAT(1I4,13I5)
9 FORMAT(3X,*MAX = ',15,3X,*MIN = ',15,3X,*N = ',15)
10 FORMAT(1X,2I5,2F10.2)
11 FORMAT(3F15.5)
12 ICJ=90
13 INM=99
14 DO 15 J=1,INM
15 TSC1(J)=0
16 READ(5,7)BM,EP2,SIG2,TD2
17 WRITE(6,21)M,ER2,SIG2,TD2
18 READ(5,7)AM,CM#,ER3,SIG3,TD3
19 WRITE(6,21)M,CM#,FR3,SIG3,TD3
20 READ(5,8)TRISG,IGATN,NEAR,ISCAT,IWR,NGEN,NM,NP
21 WRITE(6,8)TRISG,IGATN,NEAR,ISCAT,IWR,NGFN,NM,NP
22 READ(5,7)FMC,PHA,T4,PHI,TH1,PHS,THS
23 WRITE(6,21)FMC,PHA,T4,PHI,TH1,PHS,THS
24 DO 22 J=1,NM
25 READ(5,9)IA(J),IR(J)
26 WRITE(6,8)J,IA(J),IR(J)
27 DO 40 I=1,NP
28 READ(5,11)X(I),Y(I),Z(I)
29 WRITE(6,41)X(I),Y(I),Z(I)
30 READ(5,11)XP,YP,ZP
31 XX=XP
32 YY=YP
33 ZZ=ZP
34 FH7=F4C*1.E6
35 OMEGA=1P0*FH2
36 IF(1SIG2.LT.0.)JEP2=ER2*EO*DCMPLX(1.0D0,-TD2)
37 IF(1TR2.LT.0.)JEP2=DCMPLX(FR2*EO,-SIG2/OMEGA)
38 IF(1SG3.LT.0.)JEP3=ER3*EO*DCMPLX(1.0D0,-TD3)
39 IF(1T3.LT.0.)JEP3=DCMPLX(FR3*EO,-SIG3/OMEGA)
40 IF(1T4.LT.0.)JEP4=DCMPLX(FR4*EO,-SIG4/OMEGA)
41 IF(1T5.LT.0.)JEP5=DCMPLX(FR5*EO,-SIG5/OMEGA)
42 IF(1T6.LT.0.)JEP6=DCMPLX(FR6*EO,-SIG6/OMEGA)
43 IF(1T7.LT.0.)JEP7=DCMPLX(FR7*EO,-SIG7/OMEGA)
44 IF(1T8.LT.0.)JEP8=DCMPLX(FR8*EO,-SIG8/OMEGA)
45 IF(1T9.LT.0.)JEP9=DCMPLX(FR9*EO,-SIG9/OMEGA)
46 IF(1T10.LT.0.)JEP10=DCMPLX(FR10*EO,-SIG10/OMEGA)
47 IF(1T11.LT.0.)JEP11=DCMPLX(FR11*EO,-SIG11/OMEGA)
48 IF(1T12.LT.0.)JEP12=DCMPLX(FR12*EO,-SIG12/OMEGA)
49 IF(1T13.LT.0.)JEP13=DCMPLX(FR13*EO,-SIG13/OMEGA)
50 IF(1T14.LT.0.)JEP14=DCMPLX(FR14*EO,-SIG14/OMEGA)
51 IF(1T15.LT.0.)JEP15=DCMPLX(FR15*EO,-SIG15/OMEGA)
52 IF(1T16.LT.0.)JEP16=DCMPLX(FR16*EO,-SIG16/OMEGA)
53 IF(1T17.LT.0.)JEP17=DCMPLX(FR17*EO,-SIG17/OMEGA)
54 IF(1T18.LT.0.)JEP18=DCMPLX(FR18*EO,-SIG18/OMEGA)
55 IF(1T19.LT.0.)JEP19=DCMPLX(FR19*EO,-SIG19/OMEGA)
56 IF(1T20.LT.0.)JEP20=DCMPLX(FR20*EO,-SIG20/OMEGA)
57 IF(1T21.LT.0.)JEP21=DCMPLX(FR21*EO,-SIG21/OMEGA)
58 IF(1T22.LT.0.)JEP22=DCMPLX(FR22*EO,-SIG22/OMEGA)
59 IF(1T23.LT.0.)JEP23=DCMPLX(FR23*EO,-SIG23/OMEGA)
60 IF(1T24.LT.0.)JEP24=DCMPLX(FR24*EO,-SIG24/OMEGA)
61 IF(1T25.LT.0.)JEP25=DCMPLX(FR25*EO,-SIG25/OMEGA)
62 IF(1T26.LT.0.)JEP26=DCMPLX(FR26*EO,-SIG26/OMEGA)
63 IF(1T27.LT.0.)JEP27=DCMPLX(FR27*EO,-SIG27/OMEGA)
64 IF(1T28.LT.0.)JEP28=DCMPLX(FR28*EO,-SIG28/OMEGA)
65 IF(1T29.LT.0.)JEP29=DCMPLX(FR29*EO,-SIG29/OMEGA)
66 IF(1T30.LT.0.)JEP30=DCMPLX(FR30*EO,-SIG30/OMEGA)
67 IF(1T31.LT.0.)JEP31=DCMPLX(FR31*EO,-SIG31/OMEGA)
68 IF(1T32.LT.0.)JEP32=DCMPLX(FR32*EO,-SIG32/OMEGA)
69 IF(1T33.LT.0.)JEP33=DCMPLX(FR33*EO,-SIG33/OMEGA)
70 IF(1T34.LT.0.)JEP34=DCMPLX(FR34*EO,-SIG34/OMEGA)
71 IF(1T35.LT.0.)JEP35=DCMPLX(FR35*EO,-SIG35/OMEGA)
72 IF(1T36.LT.0.)JEP36=DCMPLX(FR36*EO,-SIG36/OMEGA)
73 IF(1T37.LT.0.)JEP37=DCMPLX(FR37*EO,-SIG37/OMEGA)
74 IF(1T38.LT.0.)JEP38=DCMPLX(FR38*EO,-SIG38/OMEGA)
75 IF(1T39.LT.0.)JEP39=DCMPLX(FR39*EO,-SIG39/OMEGA)
76 IF(1T40.LT.0.)JEP40=DCMPLX(FR40*EO,-SIG40/OMEGA)
77 IF(1T41.LT.0.)JEP41=DCMPLX(FR41*EO,-SIG41/OMEGA)
78 IF(1T42.LT.0.)JEP42=DCMPLX(FR42*EO,-SIG42/OMEGA)
79 IF(1T43.LT.0.)JEP43=DCMPLX(FR43*EO,-SIG43/OMEGA)
80 IF(1T44.LT.0.)JEP44=DCMPLX(FR44*EO,-SIG44/OMEGA)
81 IF(1T45.LT.0.)JEP45=DCMPLX(FR45*EO,-SIG45/OMEGA)
82 IF(1T46.LT.0.)JEP46=DCMPLX(FR46*EO,-SIG46/OMEGA)
83 IF(1T47.LT.0.)JEP47=DCMPLX(FR47*EO,-SIG47/OMEGA)
84 IF(1T48.LT.0.)JEP48=DCMPLX(FR48*EO,-SIG48/OMEGA)
85 IF(1T49.LT.0.)JEP49=DCMPLX(FR49*EO,-SIG49/OMEGA)
86 IF(1T50.LT.0.)JEP50=DCMPLX(FR50*EO,-SIG50/OMEGA)
87 IF(1T51.LT.0.)JEP51=DCMPLX(FR51*EO,-SIG51/OMEGA)
88 IF(1T52.LT.0.)JEP52=DCMPLX(FR52*EO,-SIG52/OMEGA)
89 IF(1T53.LT.0.)JEP53=DCMPLX(FR53*EO,-SIG53/OMEGA)
90 IF(1T54.LT.0.)JEP54=DCMPLX(FR54*EO,-SIG54/OMEGA)
91 IF(1T55.LT.0.)JEP55=DCMPLX(FR55*EO,-SIG55/OMEGA)
92 IF(1T56.LT.0.)JEP56=DCMPLX(FR56*EO,-SIG56/OMEGA)
93 IF(1T57.LT.0.)JEP57=DCMPLX(FR57*EO,-SIG57/OMEGA)
94 IF(1T58.LT.0.)JEP58=DCMPLX(FR58*EO,-SIG58/OMEGA)
95 IF(1T59.LT.0.)JEP59=DCMPLX(FR59*EO,-SIG59/OMEGA)
96 IF(1T60.LT.0.)JEP60=DCMPLX(FR60*EO,-SIG60/OMEGA)
97 IF(1T61.LT.0.)JEP61=DCMPLX(FR61*EO,-SIG61/OMEGA)
98 IF(1T62.LT.0.)JEP62=DCMPLX(FR62*EO,-SIG62/OMEGA)
99 IF(1T63.LT.0.)JEP63=DCMPLX(FR63*EO,-SIG63/OMEGA)
100 IF(1T64.LT.0.)JEP64=DCMPLX(FR64*EO,-SIG64/OMEGA)
101 IF(1T65.LT.0.)JEP65=DCMPLX(FR65*EO,-SIG65/OMEGA)
102 IF(1T66.LT.0.)JEP66=DCMPLX(FR66*EO,-SIG66/OMEGA)
103 IF(1T67.LT.0.)JEP67=DCMPLX(FR67*EO,-SIG67/OMEGA)
104 IF(1T68.LT.0.)JEP68=DCMPLX(FR68*EO,-SIG68/OMEGA)
105 IF(1T69.LT.0.)JEP69=DCMPLX(FR69*EO,-SIG69/OMEGA)
106 IF(1T70.LT.0.)JEP70=DCMPLX(FR70*EO,-SIG70/OMEGA)
107 IF(1T71.LT.0.)JEP71=DCMPLX(FR71*EO,-SIG71/OMEGA)
108 IF(1T72.LT.0.)JEP72=DCMPLX(FR72*EO,-SIG72/OMEGA)
109 IF(1T73.LT.0.)JEP73=DCMPLX(FR73*EO,-SIG73/OMEGA)
110 IF(1T74.LT.0.)JEP74=DCMPLX(FR74*EO,-SIG74/OMEGA)
111 IF(1T75.LT.0.)JEP75=DCMPLX(FR75*EO,-SIG75/OMEGA)
112 IF(1T76.LT.0.)JEP76=DCMPLX(FR76*EO,-SIG76/OMEGA)
113 IF(1T77.LT.0.)JEP77=DCMPLX(FR77*EO,-SIG77/OMEGA)
114 IF(1T78.LT.0.)JEP78=DCMPLX(FR78*EO,-SIG78/OMEGA)
115 IF(1T79.LT.0.)JEP79=DCMPLX(FR79*EO,-SIG79/OMEGA)
116 IF(1T80.LT.0.)JEP80=DCMPLX(FR80*EO,-SIG80/OMEGA)
117 IF(1T81.LT.0.)JEP81=DCMPLX(FR81*EO,-SIG81/OMEGA)
118 IF(1T82.LT.0.)JEP82=DCMPLX(FR82*EO,-SIG82/OMEGA)
119 IF(1T83.LT.0.)JEP83=DCMPLX(FR83*EO,-SIG83/OMEGA)
120 IF(1T84.LT.0.)JEP84=DCMPLX(FR84*EO,-SIG84/OMEGA)
121 IF(1T85.LT.0.)JEP85=DCMPLX(FR85*EO,-SIG85/OMEGA)
122 IF(1T86.LT.0.)JEP86=DCMPLX(FR86*EO,-SIG86/OMEGA)
123 IF(1T87.LT.0.)JEP87=DCMPLX(FR87*EO,-SIG87/OMEGA)
124 IF(1T88.LT.0.)JEP88=DCMPLX(FR88*EO,-SIG88/OMEGA)
125 IF(1T89.LT.0.)JEP89=DCMPLX(FR89*EO,-SIG89/OMEGA)
126 IF(1T90.LT.0.)JEP90=DCMPLX(FR90*EO,-SIG90/OMEGA)
127 IF(1T91.LT.0.)JEP91=DCMPLX(FR91*EO,-SIG91/OMEGA)
128 IF(1T92.LT.0.)JEP92=DCMPLX(FR92*EO,-SIG92/OMEGA)
129 IF(1T93.LT.0.)JEP93=DCMPLX(FR93*EO,-SIG93/OMEGA)
130 IF(1T94.LT.0.)JEP94=DCMPLX(FR94*EO,-SIG94/OMEGA)
131 IF(1T95.LT.0.)JEP95=DCMPLX(FR95*EO,-SIG95/OMEGA)
132 IF(1T96.LT.0.)JEP96=DCMPLX(FR96*EO,-SIG96/OMEGA)
133 IF(1T97.LT.0.)JEP97=DCMPLX(FR97*EO,-SIG97/OMEGA)
134 IF(1T98.LT.0.)JEP98=DCMPLX(FR98*EO,-SIG98/OMEGA)
135 IF(1T99.LT.0.)JEP99=DCMPLX(FR99*EO,-SIG99/OMEGA)
136 IF(1T100.LT.0.)JEP100=DCMPLX(FR100*EO,-SIG100/OMEGA)

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      ETA=CDOSORT(U0/EP3)                                                    R JL00560
      GAM=OMEGA*CDOSORT((-U0*EP3))                                    R JL00570
      CALL PLSORT(IA,IB,11,12,13,JA,JR,MD,ND,NM,NP,N,MAX,MIN,[CJ,INM]    R JL00580
      WRITE(6,5)
      WRITE(6,9)MAX,MIN,N                                                R JL00590
      WRITE(6,5)
      IF(MAX.GT.4 .OR. MIN.LT.1 .OR. N.GT.10)IGO TO 800            R JL00600
      INT=4                                                                R JL00610
      T12=1                                                                R JL00620
      DO 60 J=1,NM                                                        R JL00630
      VG(J)=(-0.,0.)                                                    R JL00640
      ZLD(J)=(-0.,0.)                                                    R JL00650
      JJ=J+NM                                                            R JL00660
      VG(JJJ)=(-0.,0.)                                                R JL00670
      60 ZLD(JJJ)=(-0.,0.)                                            R JL00680
      IF(INGEN.GT.0)VG(INGEN)=(1.,0.)
      CALL SGANT(IA,IB,INN,INT,ISC,IL,I2,I3,JA,JR,MD,N,ND,NM,NP    R JL00720
      2,AM,RM,C,CGD,CMM,D,FP2,EP3,ETA,FHZ,GAM,SGD,X,Y,Z,ZLD,ZS)    R JL00730
      IFEN.LE.0IGO TO 800                                            R JL00740
      IF(INGEN.LE.0IGO TO 400                                        R JL00750
      CALL GANT1(IA,IB,TIN,TIN,INR,IL,I2,I3,I12,JA,JR,MD,N,ND,NM,AM    R JL00760
      2,C,CJ,CG,CMM,D,EFF,GAM,GG,CGD,SGD,VG,Y11,Z11,ZLD,ZS)    R JL00770
      GO TO 867                                                        R JL00780
      963 DO 100 I=1,N                                                R JL00790
      ID=(I-1)*N-(I*T-1)/2                                        R JL00800
      DO 100 J=1,N                                                    R JL00810
      IJ=ID+J                                                        R JL00820
      100 WRITE(6,10)I,J,C(IJ)                                    R JL00830
      867 CONTINUE
      WRITE(6,5)
      WRITE(6,3)EFF,GG,Z11                                            R JL00840
      200 IF(INEAR.LE.0IGO TO 300                                    R JL00850
      C      LOOP TO CALCULATE NEAR ZONE PATTERN                R JL00860
      C      INPUT DIMENSIONS IN FEET                                R JL00870
      C      ZZP IS ELEVATION ABOVE GROUND                        R JL00880
      C      XXP IS CLOSEST DISTANCE FROM TRANSMITTER          R JL00890
      C      YYP IS FARTHEST DISTANCE                                R JL00900
      C
      NPTSRL=ZP                                                        R JL00910
      XMNRPL=XXP                                                    R JL00920
      XMAXPL=YYP                                                    R JL00930
      WRITE(6,345) NPTSRL, XMNRL, XMAXRL                        R JL00940
      345 FORMAT (15.7F15.5)
      C      FOR VARIOUS POINTS OF X,Y,Z.
      C      TO COMPUTE VALUES AT DIFFERENT ALTITUDES
      DO 999 TZHT = 1,3                                            R JL01000
      77P = 500.0                                                    R JL01010
      IF(TZHT.EQ.2) ZZP = 1000.00                                R JL01020
      IF(TZHT.EQ.3) ZZP = 1500.00                                R JL01030
      C      GO TO 94                                                R JL01040
      99 CONTINUE                                                    R JL01050
      R JL01060
      R JL01070
      R JL01080
      R JL01090
      R JL01100

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C FOR POINTS ALONG A SECTOR OF CONSTANT RADIUS.          RJL01110
C
C DO 547 IRJL=1,NPTSRL                                RJL01120
RADIUS = XXP+FLDAT(IRJL-1)*(YYP-XXP)/FLDAT(NPTSRL)    RJL01130
DO 547 ICUT=1,60                                         RJL01140
7P=7P/3.281                                              RJL01150
XP=RADIUS*DOS(FLOAT(ICUT-1)*PI/180.0)                RJL01160
YP=RADIUS*DSN(FLOAT(ICUT-1)*PI/180.0)                RJL01170
GO TO 59                                              RJL01180
RJL01190
RJL01200
RJL01210
RJL01220
RJL01230
RJL01240
RJL01250
RJL01260
RJL01270
RJL01280
RJL01290
RJL01300
RJL01310
RJL01320
RJL01330
RJL01340
RJL01350
RJL01360
RJL01370
RJL01380
RJL01390
RJL01400
RJL01410
RJL01420
RJL01430
RJL01440
RJL01450
RJL01460
RJL01470
RJL01480
RJL01490
RJL01500
RJL01510
RJL01520
RJL01530
RJL01540
RJL01550
RJL01560
RJL01570
RJL01580
RJL01590
RJL01600
RJL01610
RJL01620
RJL01630
RJL01640
RJL01650

C CONTINUE
C FOR POINTS ALONG THE X-AXIS ONLY
C YI = 6076.412*1.00 - 200.0
C XI = 6076.412*1.00 + 200.0
C NP = 50
C NNP = 51
C DX = (XI-XI)/FLOAT(NP)
C DO = XI
C DO 97 I = 1,NNP
C XP = (DO + FLOATE(I-1)*XI/3.281
C YP = 0.0
C 7P = 7P/3.281
C GO TO 99
C
C CONTINUE
C FOR POINTS ALONG THE Y-AXIS ONLY
C
C YI = -500.0
C YF = 500.0
C NP = 100
C NNP = 101
C DY = (YF-YI)/FLOAT(NP)
C DO = YI
C DO 97 I = 1,NNP
C XP = 23300.0/3.281
C YP = (DO + FLOATE(I-1)*DY1/3.281
C 7P = 7P/3.281
C GO TO 99
C
C CONTINUE
C POINTS ALONG THE X-AXIS IN 0AD WITH RESPECT TO THE DKG
C TRANSMITTER
C
C XI = 15200.0
C XF = 15717.0
C NP = 100
C NNP = 101
C DX = (XF-XI)/FLOAT(NP)
C DO = XI
C DO 97 I = 1,NNP
C AM = (DO + FLOATE(I-1)*DX
C GRAD = 0.0
C GO TO 99

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R.D. = -13324.09          R.JL01650
YM = GRAD*XM + RR          R.JL01670
XP = XM/3.281              R.JL01680
YP = YM/3.281              R.JL01690
ZP = 5.0/3.281              R.JL01700
GO TO 99                   R.JL01710
R.JL01720
C
93  CONTINUE                R.JL01730
C
C POINTS ALONG THE ACCESS ROAD WITH RESPECT TO THE CMH          R.JL01740
C TRANSMITTER               R.JL01750
C
C
X1 = 70715.0                R.JL01760
XF = 71215.0                R.JL01770
NP = 200                     R.JL01780
NNP = 201                     R.JL01790
DX = (XF-X1)/FLOAT(NP)      R.JL01800
DO = X1                      R.JL01810
DO 84 I = 1,NNP              R.JL01820
XM = DO + FLOAT(I-1)*DX      R.JL01830
GRAD = -0.655                 R.JL01840
RR = 46675.83                 R.JL01850
YM = GRAD*XM + RR             R.JL01860
XP = XM/3.281                 R.JL01870
YP = YM/3.281                 R.JL01880
ZP = 5.0/3.281                 R.JL01890
GO TO 99                     R.JL01900
R.JL01910
R.JL01920
R.JL01930
R.JL01940
R.JL01950
C
99  CONTINUE                R.JL01960
C
CALL GNFLO(IA,IB,INM,I1,I2,I3,ND,N,ND,NM,AM,CGD,SGD,ETA,GAM) R.JL01970
? ,CJ,Y,Z,XP,YP,ZP,EX,EY,FZ,FUX,EUY,EUZ)
XP = XP*3.281                  R.JL01980
YP = YP*3.281                  R.JL01990
ZP = ZP*3.281                  R.JL02000
WHITE(4,31)XP,YP,ZP           R.JL02010
FORMAT (3X,3E10.1)             R.JL02020
WHITE(6,6E1FX,FY,EZ,EUX,EUY,EUZ)
66 FORMAT (3E2X,2D12.4)
RATIO1 = CDARS(EX)/CDABS(EZ)    R.JL02040
RATIO2 = CDARS(EUX)/CDABS(FUZ)   R.JL02050
RATIO3 = CDARS(EUY)/CDABS(EUZ)   R.JL02060
WRITE (6,32) RATIO1,RATIO2,RATIO3   R.JL02070
32 FORMAT(15X,3E10.4)           R.JL02080
R.JL02090
C FIELD STRENGTH ADJUSTED FOR UNI BEACON BY MULTIPLYING THE VALUE R.JL02100
C OF ERP USED IN THE PROGRAM BY A FUDGE FACTOR.... R.JL02110
R.JL02120
R.JL02130
C FOR UNI BEACON ( ERP=0.7W ) THE FIELD STRENGTH AT 1 STATUTE R.JL02140
C MILE IS 4933.3761 MICROW/V/M OR 73.8629 DB/L MICV/M. R.JL02150
R.JL02160
FUDGE=4410.3273                R.JL02170
UPLO=(F7*EUZ)*1000000.0         R.JL02180
F7=F7*1000000.                 R.JL02190
EUZ=EUZ*1000000.                R.JL02200

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	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02210
	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02220
	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02230
	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02240
	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02250
	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02260
	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02270
	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02280
	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02290
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02300
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02310
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02320
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02330
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02340
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02350
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02360
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02370
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02380
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02390
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02400
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02410
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02420
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02430
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02440
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02450
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02460
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02470
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02480
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02490
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02500
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02510
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02520
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02530
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02540
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02550
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02560
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02570
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02580
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02590
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02600
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02610
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02620
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02630
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02640
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02650
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02660
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02670
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02680
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02690
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02700
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02710
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02720
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02730
C	1E20,*DOLG10DEFU1E*2DARS(EU21)	RJL02740

```

      TA=CDSD01100/100
      SAM=OMFGAM0SQRT(-1.0+EP3)
      CALL ALSPATTA,IR,LL,12,13,JA,JN,40,ND,NM,NP,N,MAX,MIN,ICJ,INM
      WRITE(6,51)
      WRITE(6,91)MAX,MIN,N
      WRITE(6,51)
      IF(MAX.GT.+4 .OR. MIN.LT.-1 .OR. N.GT.ICJ)GO TO 800
      INT=4
      I12=1
      DO 60 J=1,NM
      VG(J)=(.0,.0)
      ZL(J)=(.0,.0)
      JJ=J*N
      VG(JJ)=(.0,.0)
      ZL(JJ)=(.0,.0)
      60  IF(VG(J).EQ.VG(JJ))=1.0,0.)
      CALL SGMNT(11,14,INM,INT,ISG,11,12,13,JA,JN,MD,N,ND,NM,NP
      ,Z,AL,CM,CG,CM,0,EP2,EP3,ETA,FHZ,GAM,SGD,X,Y,Z,LDC,ZS)
      TENV=LFDIGU TO 800
      TENV=LFDIGU TO 400
      CALL GANTTA,IR,INM,14,11,12,14,112,JA,JN,MD,N,ND,NM,NP
      ,Z,C,CG,CS,CM,0,EP2,EP3,SGD,SUN,VG,Y1,Z1,L0,ZS)
      GO TO 867
      663  DO 100 I=1,N
      I0=(I-1)*N+(I+I-1)/2
      DO 100 J=1,N
      JJ=I0+J
      100  WRITE(6,101)I,J,C(I,J)
      867  CONTINUE
      WRITE(6,868)
      200  IF(INFARLE.EQ.0)GO TO 300
      200  TO CALCULATE NEAR ZONE PATTERN
      C  INPUT DIMENSIONS IN FEET
      C  ZZP IS ELEVATION ABOVE GROUND
      C  YYP IS CLOSEST DISTANCE FROM TRANSMITTER
      C  YYR IS FARTHEST DISTANCE
      C
      CPTSL=ZP
      YMPL=YYR
      XMPL=YYP
      WRITE(7,365)NPTSL,XMINSL,XMAXSL
      465  FORMAT(16.7E15.5)
      C
      C  FOR VARIOUS POINTS OF X,Y,Z.
      C
      C  TO COMPUTE VALUES AT DIFFERENT ALTITUDES
      C  OF 996.1/10 = 1.3
      ZZP = 996.0
      TEE1HT.E0.21 ZZP = 1000.00
      TEE1HT.E0.31 ZZP = 1500.00
      C
      C  GO TO 97
      C
      98  CONTINUE
      R JL 01560
      R JL 00570
      R JL 00580
      R JL 00590
      R JL 00600
      R JL 00610
      R JL 00620
      R JL 00630
      R JL 01640
      R JL 00650
      R JL 00660
      R JL 00670
      R JL 00680
      R JL 00690
      R JL 01700
      R JL 00710
      R JL 01720
      R JL 00730
      R JL 01740
      R JL 01750
      R JL 01760
      R JL 01770
      R JL 01780
      R JL 00790
      R JL 00800
      R JL 00810
      R JL 00820
      R JL 00830
      R JL 00840
      R JL 00850
      R JL 00860
      R JL 00870
      R JL 00880
      R JL 00890
      R JL 008910
      R JL 008920
      R JL 008930
      R JL 008940
      R JL 008950
      R JL 008960
      R JL 008970
      R JL 008980
      R JL 008990
      R JL 01000
      R JL 01010
      R JL 01020
      R JL 01030
      R JL 01040
      R JL 01050
      R JL 01060
      R JL 01070
      R JL 01080
      R JL 01090
      R JL 01100

```

```

T C POINTS ALONG A SECTOR OF CONSTANT RADIUS.
C
C
C 97 1000.718011,NPTSRL
C XE=XXP+FLOAT((I-1)*((YYP-XXP)/FLOAT(NPTSRL))
C YE=YYP+FLOAT((I-1)*((YYP-XXP)/FLOAT(NPTSRL)))
C ZE=ZP+F3.281
C XXP=XXP+COS(FLOAT((CUT-I)*PI/180.0))
C YYP=YYP+0.5*SIN(FLOAT((CUT-I)*PI/180.0))
C ZP=ZP
C GO TO 99
C
C 97 CONTINUE
C FOR POINTS ALONG THE X-AXIS ONLY
C XI = 6076.612*1.00 - 200.0
C XE = 6076.612*1.00 + 200.0
C NNP = 50
C NNP = 51
C YY = (YE-XI)/FLOAT(NNP)
C ZI = XI
C ZI = ZI + 1.0*NP
C YP = (0.0 + FLOAT(I-1)*DX)/3.281
C YP = 0.0
C ZP = ZP/3.281
C GO TO 99
C
C 94 CONTINUE
C FOR POINTS ALONG THE Y-AXIS ONLY
C
C YI = -530.0
C YE = 530.0
C ND = 100
C NNP = 101
C YY = (YE-YI)/FLOAT(NNP)
C ZI = YI
C ZI = ZI + 1.0*NP
C YP = 2.000*0/3.281
C YP = (0.0 + FLOAT(I-1)*DY)/3.281
C ZP = ZP/3.281
C GO TO 99
C
C 94 CONTINUE
C POINTS ALONG THE ACCESS ROAD WITH RESPECT TO THE DKG
C TRANSMITTER
C
C YI = -5207.0
C XI = 5207.0
C ND = 200
C NNP = 201
C YY = (YE-XI)/FLOAT(NNP)
C ZI = XI
C ZI = ZI + 1.0*NP
C YP = (0.0 + FLOAT(I-1)*DX)
C ZP = 0.370
C
C RUL01110
C RUL01120
C RUL01130
C RUL01140
C RUL01150
C RUL01160
C RUL01170
C RUL01180
C RUL01190
C RUL01200
C RUL01210
C RUL01220
C RUL01230
C RUL01240
C RUL01250
C RUL01260
C RUL01270
C RUL01280
C RUL01290
C RUL01300
C RUL01310
C RUL01320
C RUL01330
C RUL01340
C RUL01350
C RUL01360
C RUL01370
C RUL01380
C RUL01390
C RUL01400
C RUL01410
C RUL01420
C RUL01430
C RUL01440
C RUL01450
C RUL01460
C RUL01470
C RUL01480
C RUL01490
C RUL01500
C RUL01510
C RUL01520
C RUL01530
C RUL01540
C RUL01550
C RUL01560
C RUL01570
C RUL01580
C RUL01590
C RUL01600
C RUL01610
C RUL01620
C RUL01630
C RUL01640
C RUL01650

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    X0 = -11324.04          R JL01660
    YM = GRAD0*XM + RM      R JL01670
    X0 = XM/3.281            P JL01680
    YM = YM/3.281            R JL01690
    ZP = 5.0/3.281           R JL01700
    GU TO 99                 R JL01710
    R JL01720
    C 93 CONTINUE             R JL01730
    C POINTS ALONG THE ACCESS ROAD WITH RESPECT TO THE C4H
    C TRANSMITTER
    C
    V1 = 70715.0            P JL01740
    VE = 71215.0            R JL01750
    NP = 210                 R JL01760
    NNP = 201                R JL01770
    DX = (XF-X1)/FLOAT(NP)  R JL01780
    DD = X1                  R JL01790
    DI = 46 J = 1,NNP        R JL01800
    XM = DD + FLOAT(1-1)*DX  R JL01810
    GRAD = -0.455            R JL01820
    RM = 46575.43            R JL01830
    YM = GRAD*XM + RM       R JL01840
    XP = XM/3.281            R JL01850
    VP = YM/3.281            R JL01860
    ZP = 5.0/3.281           R JL01870
    GU TO 99                 R JL01880
    R JL01890
    C 94 CONTINUE             R JL01900
    C
    CALL GMFIELD13,10,IN4,11,12,13,MU,N,ND,NM,AM,CGD,SG3,ETA,GAM R JL01940
    Z,C10,Y,XP,YP,ZP,FX,FY,FZ,EUX,EUY,EUZ R JL01950
    YM = YM/3.281            R JL01960
    VP = VP/3.281            R JL01970
    ZP = ZP/3.281            R JL01980
    WRITE(6,21)XP,YP,ZP
    21 FORMAT(1X,3F10.1)      R JL01990
    WRITE(6,6)FX,FY,FZ,FUX,FUY,EUZ R JL02000
    66 FORMAT(3(2X,2D12.6))   R JL02010
    RATI01 = CHARS(FX)/CHARS(FZ) R JL02020
    RATI02 = CHARS(FY)/CHARS(FZ) R JL02030
    RATI03 = CHARS(FUZ)/CHARS(EUZ) R JL02040
    WRITE(6,32) RATI01,RATI02,RATI03 R JL02050
    32 FORMAT(154,3F10.4)
    C
    C FIELD STRENGTH ADJUSTED FOR UNI REACON BY MULTIPLYING THE VALUE
    C OF EPR USED IN THE PROGRAM BY A FUDGE FACTOR.....
    C
    C FOR UNI REACON ( EPR=0.7K ) THE FIELD STRENGTH AT 1 STATUTE
    C MILE IS 4933.3761 MICROWATT/M 71.8629 MHZ/MICROWATT.
    C
    EUDF=2404.0054          R JL02100
    UPLDF=(1/EUDF)*(1000000.,1) R JL02110
    125*EUDF*1000000.          R JL02120
    FDF=EUDF*(1000000.)      R JL02130
    R JL02140
    R JL02150
    R JL02160
    R JL02170
    R JL02180
    R JL02190
    R JL02200
  
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C      C0151
C      GO TO RR
C
84    CONTINUE
     GO TO 300
85    CONTINUE
     GO TO 300
86    CONTINUE
     GO TO 999
87    CONTINUE
     GO TO 999
88    CONTINUE
     GO TO 999
547    CONTINUE
999    CONTINUE
S01    IF(L1GAIN.LF.01GD) TO 400
     INCJ
     PH=PHA
     TH=THA
     CALL      GFFLDIA,IR,INC,INM,INR,I1,I2,I3,I12,MD,N,ND,NM,AM
     /,ACSP,ACST,C,CGD,CG,CJ,CM,D,FCSP,FCST,EP,FT,FPP,FIT,EPPS,EPTS
     /,EFTS,EFTS,SG,GPP,GTT,PH,SGD,SCSP,SCST,SPPM,SPTM,STPM,STM,TH
     4,X,Y,Z,ZLD,ZS,ETA,GAM)
     WRTF(6,31PH,TH,GPP,GTT
     WRTF(6,31PH,TH,GPP,GTT
430    IF(L1SCAT,LF.01GD) TO 600
     INCJ
     PH=PHI
     TH=THI
     CALL      GFFLDIA,IR,INC,INM,INR,I1,I2,I3,I12,MD,N,ND,NM,AM
     /,ACSP,ACST,C,CGD,CG,CJ,CM,D,FCSP,FCST,EP,ET,FPP,FIT,EPPS,EPTS
     /,EFTS,EFTS,SG,GPP,GTT,PH,SGD,SCSP,SCST,SPPM,SPTM,STPM,STM,TH
     4,X,Y,Z,ZLD,ZS,ETA,GAM)
     WRTF(6,61PH,TH,SPPM,SPTM,STPM,STM
     WRTF(6,61PH,TH,SPPM,SPTM,STPM,STM
     S02    IF(L191SC,LF.01GD) TO 600
     INCJ
     PH=PHS
     TH=THS
     CALL      GFFLDIA,IR,INC,INM,INR,I1,I2,I3,I12,MD,N,ND,NM,AM
     /,ALSP,ACST,C,CGD,CG,CJ,CM,D,FCSP,FCST,EP,FT,FPP,FIT,EPPS,EPTS
     /,EFTS,EFTS,SG,GPP,GTT,PH,SGD,SCSP,SCST,SPPM,SPTM,STPM,STM,TH
     4,X,Y,Z,ZLD,ZS,ETA,GAM)
     WRTF(6,61PH,TH,SPPM,SPTM,STPM,STM
     W00    CONTINUE
     CALL MPLUT (XAR,7AH,51,1,1,XAPL,YAH)
W00    CALL EXIT
     END

```

Appendix C Acronyms

AC	Alternating Current
CMH	Designates particular NDB near Columbus, Ohio
dB	decibels
DC	Direct Current
DKG	Designates particular NDB near Columbus, Ohio
ERP	Effective Radiated Power
f	frequency, Hertz
KHz	Kilohertz
kV	Kilovolts
MHz	megahertz
NDB	Non-Directional Beacon
NM	nautical miles
RI	Radio Interference
s/n	signal to noise
vs	versus
ϵ_r	relative permittivity
σ	conductivity

